Reclamation and Revegetation of Land Areas Disturbed by Man

An Annotated Bibliography of Agricultural Research 1972-80

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ABSTRACT

Follett, R. F. 1980. Reclamation and Revegetation of Land Areas Disturbed by Man; An Annotated Bibliography of Agricultural Research, 1972-1980. United States Department of Agriculture, Bibliographies and Literature of Agriculture Number 8, 55 pp.

This annotative bibliography of publications, issued by the Science and Education Administration-Agricultural Research (SEA-AR) relates to the technical objectives of National Research Program 20770, a program that links research by SEA-AR to other agencies within USDA. The technological objectives of NRP 20770 are (1) integrating plans for reclamation and use of land before mining; (2) restoring disturbed areas to optimum level of agricultural productivity or other uses; (3) stabilizing disturbed areas against erosion, subsidence, and slides; (4) preventing degradation of surface and ground water in and adjacent to disturbed land areas; (5) using waste materials in reclaiming disturbed areas; and (6) improving scenic, wildlife, and aesthetic values of disturbed areas.

Key words: National Research Program 20770, reclamation, revegetation, waste materials, strip mining, surface mining, spoils.

Acknowledgment

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CONTENTS

Issued August 1980

Author Index

Author	Page(3)

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Note: Reprints of manuscripts can be obtained from the authors by addressing the request to the appropriate research location.

Reclamation and Revegetation of Land Areas Disturbed by Man

An Annotated Bibliography[1]
Agricultural Research,
1972-1980

R. F. Follett[2]

The basic plans for research on the "Reclamation and Revegetation of Land Areas Disturbed by Man" are described in National Research Program 20770 (NRP 20770). This NRP within Agricultural Research (AR) of the Science and Education Administration (SEA) of USDA outlines a 10-year plan that was initiated in May 1976. In addition, it links research by SEA-AR to major program areas involving other agencies within the USDA program structure. It serves to improve communications between scientists and management, between research managers and staff scientists, between SEA-AR and other research organizations, and between the USDA and other Departments, the private sector, and Congress.

NRP 20770 has the following technological objectives:

1. Integrate reclamation and land use plan into total mining plans prior to mining.

2. Restore disturbed areas to optimum level of agricultural productivity or other uses.

3. Stabilize disturbed areas against erosion, subsidence, and slides.

4. Prevent surface and ground water degradation in and adjacent to disturbed land areas.

5. Utilize waste materials in reclaiming disturbed areas.

6. Improve scenic, wildlife, and aesthetic values of disturbed areas.

Research is being conducted by SEA-AR locations in Fort Collins, Colo.; Beltsville, Md.; Ithaca, N.Y.; Mandan, N. Dak.; Coshocton, Ohio; University Park, Pa.; Blacksburg, Va.; Morgantown, W. Va.; and Cheyenne and Laramie, Wyo. Results from these programs and other relatively new research programs are even now being used to revegetate and reclaim

[1]Research supported in part by funds from the Environmental Protection Agency, Interagency Agreement: EPA-IAC-D5-E763; the U.S. Department of Agriculture, Forest Service, Surface Energy and Mining (SEAM) Program; the U.S. Department of Energy, Interagency Agreement: E(49-18)-2488; and the U.S. Department of the Interior, Bureau of Mines, Interagency Agreement: J0166055.

[2]National Research Program Leader, Soil Fertility and Plant Nutrition, Soil, Water and Air Sciences, National Program Staff, Science and Education Administration-Agricultural Research, U.S. Department of Agriculture, Beltsville, Md. 20705.

drastically disturbed land areas in major coal regions in the United States (fig. 1). These research results have been published in an exceedingly diverse range of scientific literature. This diversity has helped serve the needs of the scientific community and the many users of this information. Recently, the Surface Mining Control and Reclamation Act of 1977 (PL 95-87) became law. Many issues requiring research are being raised by this new law. The Office of Surface Mining Reclamation and Enforcement, a new agency within the Department of the Interior, was established by PL 95-87 and now joins other potential users of SEA-AR information.

The purpose of this publication is to establish an annotative bibliography of SEA-AR publications and to relate these publications to the technological objectives of NRP 20770. Although many publications included in this bibliography may relate to more than one technological objective, they only will be reported once. This is particularly important under technological objective 6, which deals with scenic, wildlife, and aesthetic values. Several of the other technological objectives, particularly the first three, contribute to this last objective. All the objectives contribute information relative to the interpretation and implementation of PL-95-87.

Overview of the Problem

The total land area disturbed by surface mining in the United States currently exceeds 4 million acres. About half of this area results from coal-mining operations. Sand and gravel mining accounts for about 25 percent. The remaining 25 percent includes stone, gold, clay, phosphate, iron, and all other mining operations. All mining operations probably will increase over the next few years. A conservative estimate is that more than one-third of the total land surface in the United States may be disturbed seriously by man at some time in the future. Disturbances would be caused by mining for minerals and fossil fuels and large construction projects. Desirable reclamation and revegetation procedures will become increasingly important.

Technology is presently available to reclaim most land areas where the disturbances are minor, involving only the surface and subsoil, and encompassing relatively small areas. Technology is not available, however, for reclaiming many large land areas that have been disturbed to depths below the subsoil. Coal mining, which is responsible for about half of the present disturbed land areas, will increase and continue to be the most critical in terms of total land disturbance. At the turn of the century, production of bituminous coal and lignite was about 200 million tons per year. By 1978, production was up to 654 million, and we probably will be mining over 1 billion tons annually by 1985 and 2 billion by the year 1995, with about 57 percent of the total removed by surface mining methods.[3] These estimates may be conservative if we are forced to convert coal to help meet our petroleum needs. With present technology, 1 ton of bituminous coal can be converted to 2 barrels or more of oil or would provide electricity for the average household for about 2 months.

[3] U.S. Department of Energy. 1978. Annual Report to Congress by the Energy Information Administration, vol. 3, 432 p.

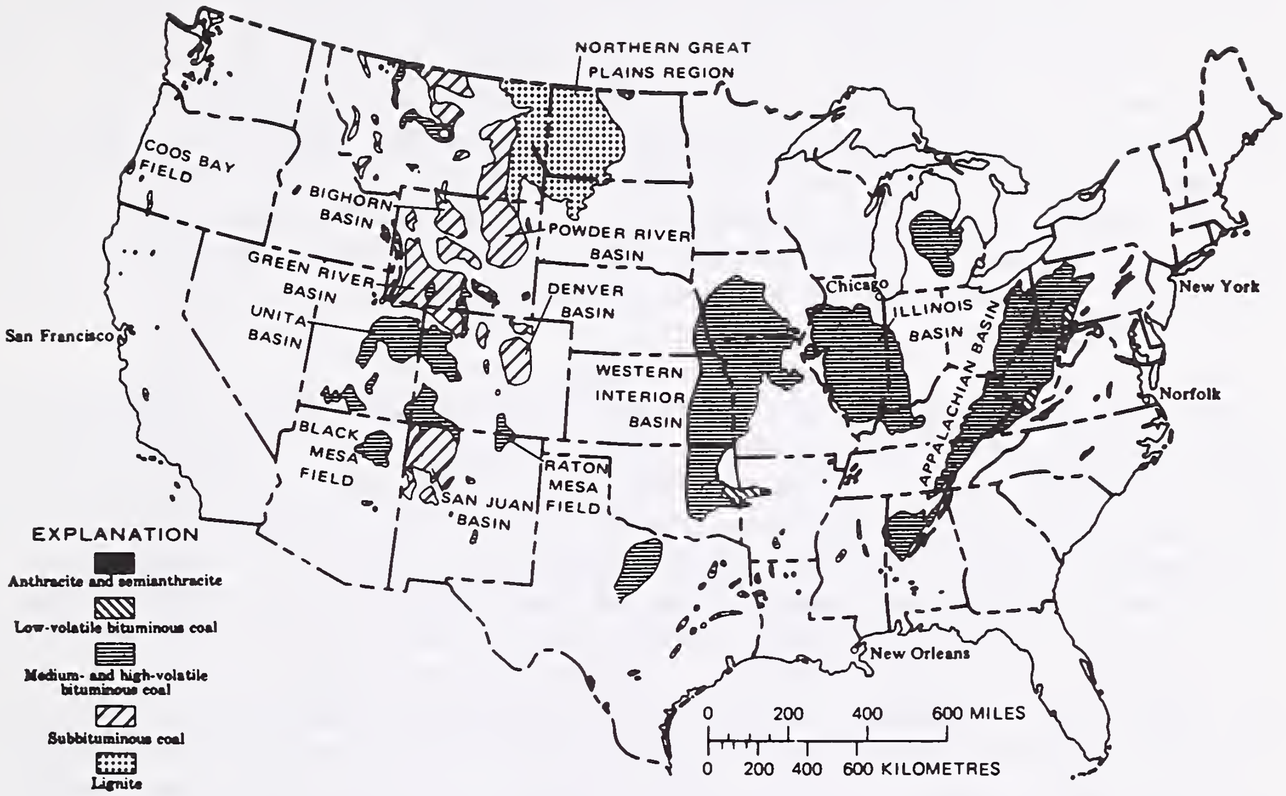

Figure 1.--Coal fields of the conterminous United States.

The percentage of coal mined by surface methods is increasing. In 1917, strip mining accounted for only 1 percent of the total coal mined in this country. By 1968, this figure had risen to 35 percent, and by 1973 strip mining accounted for over half the coal mined. The percentage removed by surface mining will continue to increase because of the advantages of surface mining over underground mining. The output per worker day is more than three times as great. Operating costs are 35 to 40 percent, compared with 50 percent from underground mines. Furthermore, 70 percent of the bituminous coal and lignite reserves are west of the Mississippi River in areas in which the terrain ideally is suited for strip mining. It is understandable, therefore, why 100 percent of the coal mined in North Dakota, Montana, and Alaska during 1973 was removed by surface mining. As these vast coal fields are expanded, the disturbed land areas will increase. The U.S. Geological Survey estimates that some 4,287 square miles of land may be stripped by 1980. Removing the rest of the coal now believed to be recoverable by strip mining will disturb 71,000 square miles.

Reclamation practices must be designed for specific areas of the country because the problems are different in different areas. In the Eastern United States, coal is mined in very rugged terrain, typified by steep mountains and narrow valleys. The nearly horizontal bituminous coal seams are exposed by scrapping off the overburden. This leaves an almost level bench that follows the contour around the mountains, an exposed high wall, and a steep outer slope consisting of overburden pushed down the side of the mountain. This denuded area contributes millions of tons of sediment and acid to the streams. Sixty percent of the stripped land is eroded or subject to erosion. Massive slides are a problem on almost 4,000 miles of the steep outer slopes. Acid drainage has seriously polluted nearly 6,000 miles of streams; surface mining has contributed about 12 percent of the total. Spoil materials are highly variable, consisting of soil, subsoil, and unweathered rocks. They are practically devoid of organic matter and plant nutrients. Contents of nitrogen, phosphorus, potassium, calcium, and magnesium are too low to support adequate plant growth, and trace elements may be deficient or toxic. The very low water-holding capacity (ranging from 4 to 12 percent) and the highly dispersed clays result in a seedbed that is often too dry and covered with a crust nearly impermeable to water or to emerging seedlings.

The topography of coal-producing areas in the West is generally gently rolling. Stripping involves digging a trench through the overburden. Once the coal is removed, a second trench is dug adjacent and parallel to the first. Until 2 or 3 years ago, the overburden from this trench was deposited in the first cut. Series of roughly parallel ridges and valleys finally appeared in which the topsoil often was buried and the material originally just above the coal seam was exposed. In the last 2 or 3 years, most Western States have enacted strip mine laws that require stockpiling the topsoil for later placement over the spoil. Acidity is not usually a problem in the western fields. The exposed materials are low in organic matter, however, and sometimes extremely fine-textured. These materials contain large amounts (sometimes over 40 percent) of montmorillonitic clay, which expands and contracts upon wetting and drying. Since the clay is moderately saline, low in organic matter and sometimes highly sodic, the

spoil materials are extremely unstable and highly impermeable to water. Low rainfall in the West adds to the reclamation problem. Without supplemental irrigation, reclamation of disturbed areas has little chance of success where the annual rainfall is 10 inches or less.

Although land disturbed by coal mining is and will continue to be of major concern, the problems associated with oil shale mining and processing will become more significant in the near future. Because of the petroleum shortage, oil shale mining probably will become a major contributor to disturbed land areas. About 30 States have oil shale deposits. The most important deposits are in the Green River formation and cover about 16,500 square miles in Colorado, Utah, and Wyoming. The principal oil shale area is in the Piceance Basin of Colorado, which covers 1,350 square miles. The deposits are about 2,000 feet thick in the center of the basin and assay at about 25 gallons per ton. Both deep mining and surface mining will be used to recover the shale. In addition to problems in reclaiming the spoil material, the spent shale must be disposed of and the disposal site must be reclaimed. The spent shale occupies more volume than the original shale. Characteristics of the spent shale depend upon the process used. For example, spent shale from the TOSCO process is divided finely--90 percent is the size of silt or smaller--highly saline, black, and devoid of most plant nutrients. No satisfactory method is available for disposing of the spent shale. One can visualize the magnitude of this problem by considering that a processing plant producing 50,000 barrels/day would cover an 80-acre area to a depth of 100 feet with spent shale every year.

The problem of reclaiming disturbed land areas is of major importance today. It will become more urgent in the next 5 to 10 years because the current petroleum crisis is increasing the demand for coal. Therefore, research is needed to develop more reliable and economical technology to meet the increasing demand for reclamation of the disturbed areas. Although much of this research is cooperative with State agricultural experiment stations, industry, and other groups, only the SEA-AR program will be described here. Because of its national scope, this research supports and contributes to programs of such action and regulatory agencies as the Environmental Protection Agency; Science and Education Administration--Extension, Forest Service, and Soil Conservation Service of the U.S. Department of Agriculture; the U.S. Department of Energy; and Office of Surface Mining, Bureau of Land Management, and Bureau of Mines of the U.S. Department of the Interior.

Visualized Technology

1. It is envisioned that complete reclamation plans need to be developed before the start of the mining operation. These plans would include inventory of chemical and physical properties of overburden and soils, highest potential use of land after mining, and separation and stockpiling of soils or overburden material according to quality. Most desirable soils or overburden materials are planned on the surface to provide a landscape suitable for establishing and maintaining the most desirable vegetative cover during and after mining operations.

2. Disturbed land areas will be restored in their potential for agricultural productivity or other use by obtaining information on chemical

properties of spoil materials; identifiying toxic concentrations of elements; developing specialized soil-testing procedures; placing soil and overburden material to promote best soil formation and availability of plant nutrients; devising soil, water, and plant management systems to meet specific environmental conditions existing at different locations; selecting and breeding plant species and genotypes that will persist over a long time and can be used under variable and sometimes adverse physical, chemical, and environmental conditions; and determining the effects of microbial activity on breakdown of primary and secondary minerals for soil formation, and on the release of necessary elements for plant growth.

3. Technology will be developed to stabilize disturbed land areas and insure that newly disturbed areas can be stabilized as soon as possible after completing the mining operation and to alter mining operations, if needed, to insure stability.

4. Technology will be developed to minimize water pollution, restore the original or a more desirable hydrologic cycle, and enhance water quality in the disturbed areas. This technology will be achieved by obtaining valid data on the hydrologic cycle and water quality of the areas before and after mining, identifying desired physical and chemical properties of final spoils resulting from use of suitable grading and earth-moving techniques, using soil and other surface management practices, and by developing special soil and crop management practices to control infiltration, percolation, and runoff.

5. Technology will be developed to permit safe and economical use of domestic and industrial waste materials while providing for complete chemical and physical characterization of wastes, determine effective loading rates to permit maximum utilization of plant nutrients, identify potentially toxic elements, and determine ways of chemically and physically binding these elements; and determine effects of such environmental factors as exposure, elevation, and temperature on uptake of elements for plant species. In addition, special soil, water, and crop management practices will be developed to optimize use of waste materials without degrading surface- or ground-water quality.

6. Technology will be developed to restore land areas to optimum use and to provide maximum scenic, wildlife, and aesthetic value to all types of disturbed land by identifying growth requirements of plant species and varieties used for specialized purposes; improving scenic and aesthetic value of the area; identifying potential parks and recreational areas before mining; and using special land-forming and regrading techniques to provide desired watershed characteristics, recreational facilities, and wildlife habitats.

List of Publications

The following publications are listed by location and the technological objective towards which the publication makes its major contribution.

TECHNOLOGICAL OBJECTIVE 1

Integrate reclamation and land use plan into total mining plans before mining.

Beltsville, Md.

Armiger, W. H., J. N. Jones, Jr., and O. L. Bennett.
1976. Revegetation of land disturbed by strip mining of coal in Appalachia. U.S. Department of Agriculture, Agricultural Research Service, Northeastern Region, ARS-NE-71, pp. 1-38. (Series discontinued, Agricultural Research Service is now Science and Education Administration-Agricultural Research.)

This publication reports research to reveal and resolve problems associated with the revegetation of surface mine spoils in Northern Appalachia. Much of the research was conducted in West Virginia. An approach to revegetation problems is discussed that causes the physical and chemical characteristics of mine spoils. Soil amendments, mulches, and plant species alone and in various mixtures were evaluated for persistence and ground cover. Bermudagrass was studied to see if it could adapt climatically to the higher elevations in mountainous terrain. Native strains plus Midland and Tufcote varieties were tested on very acid spoils. Other rhizomatous plants included in field studies were switchgrass and flatpea. These species are drought resistant, a characteristic needed in revegetation of mine spoils.

Such surface-mined sites in Appalachia can be revegetated if the physical and chemical restraints can be identified and corrected through utilization of proper soil amendments. Plant species environmentally adapted to the region also are required. Collective efforts of the surface mine operators, landowners, and State and Federal agencies are indispensable to expedite reclamation.

Mandan, N. Dak.

Bauer, A., W. A. Berg, and W. L. Gould.
1978. Correction of nutrient deficiencies and toxicites in strip-mined lands in semiarid and arid regions. In Reclamation of drastically disturbed lands: Symposium proceedings, Wooster, Ohio, August 9-12, 1976. pp. 451-466. Frank W. Schaller and Paul Sutton, editors. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, Wis.

Soil test procedures presently utilized detect nutrient deficiencies. Interpretations of soil tests relative to rate of fertilizer application

needed to correct the deficiency, however, may depend on the kind of plant-rooting medium present at the spoil surface and its thickness. Where the plant-rooting medium consists of soil materials from essentially all of the solum, corrective rates of fertilizers and other soil amendments may be expected to equal those required on undisturbed soils of equal deficiency. As the thickness of organic matter-containing plant rooting medium decreases, however, corrective rates for a given deficiency level should be higher if another factor does not alter the potential yield level of the crop grown.

Doering, E. J., and W. O. Willis.
1975. Chemical reclamation of sodic strip-mine spoils. U.S. Department of Agriculture, Agricultural Research Service, North Central Region, ARS-NC-20, 8 p. (Agricultural Research Service is now Science and Education Administration-Agricultural Research)

This study shows that the hydraulic conductivity of sodic strip-mined spoils is established and maintained at an acceptable level by leaching with water high in salts. Sodic spoil material can be reclaimed chemically by using highly soluble calcium salt. An example showed that the salt required for chemical reclamation of the spoil material used would cost more than $1,300 per acre per foot of depth reclaimed. These data indicated that chemical reclamation is effective, but it is not recommended for large scale application on strip-mined spoils because of the cost. A better alternative is to apply a suitable thick layer of nonsodic topsoil and subsoil on the strip-mined spoils.

Gee, G. W., and A. Bauer.
1976. Chemical and physical properties of stockpiled materials at a minesite in western North Dakota. North Dakota Agricultural Experiment Station Farm Research 34(2):44-51.

The chemical and physical properties tested indicated that stockpiled materials reflect the mixing of surface and subsurface (A, B, and perhaps C horizon) materials. Stripping operations must be controlled better to segregate the soil horizon if the goal is to have materials for spreading that are physically and chemically similar to the undisturbed soils.

Merrill, S. D., F. M. Sandoval, J. F. Power, and E. J. Doering.
1980. Salinity and sodicity factors affecting suitability of materials for mined-land reclamation. _In_ Proceedings of the symposium on the adequate reclamation of mined lands? Billings, Montana, March 1980. pp. 3-1 to 3-25.

Salinity and sodicity are changeable qualities. It is necessary that the dynamics of salt and water flow that can occur in spoils or reconstructed mine soils be considered when assessing the suitability of materials for reclamation use. Spreading of soils over spoils will often leave the salinity of the upper part of the new minesoil in disequilibrium with the soil water regime. An example is given in which the salt load of saline, permeable soil placed in the profile surface position was reduced consider-

ably. Salt-tolerance data, gathered under conditions of low plant-water stress and of a limited extent of soil drying, must be translated into terms relevant to the arid or semiarid environments in which mined land is reclaimed in the West. Plants are frequently subject to water stress in these environments. Reduction of the soil solution volume by soil drying increases salinity hazard.

Elevated sodicity has a pronounced effect on infiltration and affects subsurface hydraulic conductivity. Texture and mineralogical composition of clay-fraction material greatly influence the effect of sodicity upon hydraulic conductivity, and should be considered in assessing suitability.

A gradient in soluble sodium concentration is created when sodic spoils are covered with good-quality soil. In western North Dakota experiments, soluble sodium migrated from sodic minespoil into cover soil. The relative amount of migration was significantly greater at sites where the sodium adsorption ratio (SAR) of montmorillonite-dominated spoil was greater than 20 than where it was 11 or 12. Theoretical calculations of salt diffusion and cation exchange show that, at the sites examined, the upward sodium movement was largely diffusive. Field and laboratory measurements and calculations indicate that sodium migration will cause a potentially deteriorating increase of sodicity in approximately 6 to 8 inches out of a total of 12 inches of cover soil. The conditions under which this will occur are that the buried spoil has a sufficiently high level of sodicity and has a very low hydraulic conductivity, is relatively fine-textured, and montmorillonite predominates in the clay fraction. Calculations have shown that with greater depths of cover soil, the thickness of the sodicated zone can be greater. When the hydraulic conductivity of the spoil is great enough to permit some seasonal leaching of soluble salts, we postulate that sodication of overspread soil will not be a problem.

Power, J. F., W. O. Willis, F. M. Sandoval, and J. J. Bond.
1974. Can productivity of mined land be restored in western North Dakota? North Dakota Agricultural Experiment Station Farm Research 31(6):30-32.

This paper describes foreseeable problems in reclamation of strip-mined land in North Dakota, based mostly on knowledge of physical and chemical properties of the overburden. Possible ways of correcting these problems to restore productivity are outlined.

Power, J. F., and F. M. Sandoval.
1976. Effect of sampling method on results of chemical analysis of overburden samples. Mining Congress Journal 62:31-41.

The results of an experiment are presented in which the effects of several different methods to obtain overburden samples were determined and results of chemical analysis of the materials were compared. Least contamination occurred for pneumatic drilling. Probably no single drilling method can be recommended for all conditions and types of overburden and for all sampling

purposes. These factors and others should be considered in deciding which drilling method to use. Several drilling methods may be necessary to accommodate varying conditions or materials.

Power, J. F.
1977. Mining, strip - Western United States. In McGraw-Hill Yearbook of Science and Technology, pp. 303-305.

This is a brief summary of problems and requirements for proper reclamation of mined land in the drier regions of the United States, outlining the best technology of the day. Ideally, three steps in the reclamation of land are to (1) determine physical and chemical properties of soils and overburden materials before mining; (2) relate these properties to the growth potential of different crops in a given climatic zone; and (3) develop an economically feasible mining plan whereby overburden and soil materials are deposited during mining so that plant growth potentials can be achieved.

Power, J. F., F. M. Sandoval, and R. E. Ries.
1977. Strip mining--getting the energy while keeping the environment. Crops and Soils 29(4):12-14.

This article reviews the problems encountered in reclamation and outlines the technologies developed through research to overcome these problems. Included are discussions of current technology, moisture conservation, sodium, bulk density, soil fertility and salinity of soils and spoils, and some benefits of covering spoils with soil material.

Power, J. F.
1978. Reclamation research on strip-mined land in dry regions. In Reclamation of drastically disturbed lands: Symposium proceedings, Wooster, Ohio, August 9-12, 1976, pp. 521-535. Frank W. Schaller and Paul Sutton, ed. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, Wis.

Research on the reclamation of land disturbed by strip mining for coal in dry regions is being conducted by several different organizations in each State and province of the Western United States and Canada where mining is significant. The purposes of this chapter are to outline the history of reclamation research; to describe the natural resources used in reclamation; to review the kind of research information available and describe the kind needed to properly utilize each of the natural resources; and to show how this information is used in developing reclaimed land. This chapter is an overview of the state of the art and indicates the direction needed in the future. It does not catalog the various research activities currently in progress.

Ries, R. E., F. M. Sandoval, and J. F. Power
1977. Reclamation of disturbed lands in the lignite area of the Northern Plains. In Proceedings, 1977 symposium on techology and use of lignite, pp. 309-327. Energy Research and Development Administration, and University of North Dakota, Grand Forks, N. Dak. GFERC/IC-77/1.

This paper describes the current potential and problems of reclamation and gives an overview of current reclamation work at the Northern Great Plains Research Center. Reclamation work is emphasized in the Northern Plains lignite area. Recommended procedures include analyzing soil and overburden in the laboratory before mining, removing, and stockpiling suitable soil materials (a layer up to 5 ft. thick, if available); removing overburden; extracting coal; reshaping spoil; replacing stockpiled soil material; fertilizing; and seeding to cropland or rangeland mixtures of plant species. If recommended procedures are followed, the probability for highly successful reclamation is promising. Some existing problems for which there is less knowledge include piping erosion, subsidence, the need for more reliable practices in establishing vegetation, and the assurance of sustained productivity under various land uses.

Current research is determining the thickness of soil needed over undesirable mine spoil for permanent reclamation. The use of chemical amendments also is being studied and may have a role, especially where not enough suitable soil is available to cover sodic spoils. Many plant species are being evaluated. Irrigation to supplement natural precipitation during the period of establishment also is being studied.

Ries, R. E., and A. D. Day.
1978. Use of irrigation in reclamation in dry regions. In Reclamation of drastically disturbed lands: Symposium proceedings, Wooster, Ohio, August 9-12, 1976, pp. 451-466. Frank W. Schaller and Paul Sutton, editors. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, Wis.

This chapter reviews the history and potential for use of supplemental irrigation, especially to establish stands of perennial vegetation on mined land. The need for supplemental irrigation generally has been recognized and accepted as necessary in areas where precipitation is low. Further use of irrigation as a tool in reclamation will depend upon the benefits to be gained. Much is known about irrigation use and techniques. This knowledge provides a basis for further development of techniques and principles that apply more specifically to irrigation for plant establishment. Such irrigation needs to be better understood and applied. Supplemental irrigation is a promising tool in establishing highly productive perennial plant communities on areas disturbed by mining. It also might improve deteriorated rangeland communities by establishing new communities with more desirable species.

Sandoval, F. M., and J. F. Power.
1977. Laboratory methods recommended for chemical analysis of mined-land spoils and overburden in Western United States. U.S. Department of Agriculture, Agriculture Handbook No. 525, 31 pp.

Guidelines are suggested for sampling and for chemical analysis of mine spoils and overburden samples. This handbook was compiled to meet an urgent need for uniform laboratory methods to evaluate plant growth

capabilities and limitations associated with coal lands in the Western United States. Salinity associated with sodium and nutritional deficiencies commonly characterize these materials. The procedures selected are those used by the authors and are accepted most widely as reference or standard procedures for western mined lands and associated spoils. Other methods may be equally applicable, but those presented have been related to plant growth responses and may be used as a reference for comparison with other methods.

Sandoval, F. M., and W. L. Gould.
1978. Improvement of saline- and sodium-affected disturbed lands. In Reclamation of drastically disturbed lands: Symposium proceedings, Wooster, Ohio, August 9-12, 1976, pp. 485-504. Frank W. Schaller and Paul Sutton, ed. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, Wis.

This chapter outlines reclamation problems that are unique to sites affected by sodic and saline spoils, and it provides information on the best-known technology for overcoming these unique restrictions.

The potential for revegetation is related closely to the chemical and physical characteristics of disturbed soils. The quantity and kinds of soluble salts in the plant growth medium are especially important in reclamation in the Western United States. Much of the information comes from research on agricultural soils, and shows that we can transfer much of this technology to mined land spoils. Salt-affected soils contain enough soluble salts or exchangeable medium, or both, to restrict plant growth. Excessive soil salts can make land less productive or cause complete crop failures. The accumulation of soluble salts in soils is one of the most serious problems associated with irrigation agriculture in arid regions, but salt also is a hazard in areas other than those where the problem has been emphasized.

Research on sodic soils in recent years has helped clarify the reversible equilibrium relation between soluble and exchangeable or adsorbed Na in the presence of other cations. Present knowledge indicates that the salinization and cation-exchange processes in salty soils are reversible and frequently controllable. The basic principles for reclaiming and managing these soils generally have been understood and applied for many years. Newer technology increases the potential for efficient application of this knowledge.

Blacksburg, Va.

Jones, J. N., Jr., W. H. Armiger, and O. L. Bennett
1976. Forage grasses aid the transition from spoil to soil: Proceedings of the third symposium on surface mining and reclamation, Vol. II, National Coal Conference and Exposition, II. Louisville, Ky. pp. 185-194.

Alternate land uses for mine soils can offer economic potential. Physical and chemical properties of the mine soil largely will determine the ways in which it can be used.

This paper discusses results of a 4-year study to evaluate soil amendments in revegetating surface mine spoil, the response of four grasses managed for yield, and the status of the spoil profile after 4-1/2 years. Fertility treatments included 20 combinations or rates of rock phosphate, lime, and superphosphate. Although researchers expected Ky 31 fescue to be the best species for stabilization and yield, timothy yields were higher under each soil amendment treatment. Rock phosphate produced higher yields than superphosphate or dolomitic limestone plus superphosphate. Organic matter accumulations from the four forage sods over the 4-1/2-year period averaged 1.8 percent in the 0- to 3-inch depth. Measured infiltration rates ranged from a high of 0.29 inch/hour to a low of 0.03 inch/hour. The study at Blacksburg, Va., indicated that acid mine spoil can be changed in a short time into a young mine soil through the use of good management, proper soil amendments, and adapted forage grasses.

Morgantown, W. Va.

Bennett, O. L. 1976. Mining, strip. *In* McGraw-Hill Yearbook of Science and Technology, New York, N.Y. pp. 301-303.

Some new State laws require that surface soil be removed before mining and be respread on the surface of the spoil material after mining and final grading. Even where topsoil has been replaced, the changes in physical and chemical properties of the disturbed spoils often create a hostile environment for seed germination and subsequent plant growth. Trees, shrubs, grasses, and legumes have been planted on many sites, but their survival has been hindered by improper grading techniques, low pH, lack of available plant nutrients, improper selection of adapted varieties, and climatic factors.

Research to determine desirable spoil amendments indicates that a detailed chemical analysis of the spoil material is essential to determine the presence or absence of elements necessary for plant growth and to determine those soluble elements that may be toxic to plants. Domestic and industrial waste materials are being tested as amendments on strip-mined spoils. These include digested sewage sludge, composted garbage, and fly ash. Mulching materials are needed to alter the surface microclimate and help conserve soil moisture during the critical seedling establishment period. Grass species that have shown promise for use on low-pH strip-mined spoils in the United States include weeping lovegrass, bermudagrass varieties, tall fescue, switchgrass, bent grass, deer tongue, and redtop. Commercial varieties of orchardgrass, bromegrass, ryegrass, and timothy have been used successfully on spoils treated with lime and fertilizer. Legume species tested on low-pH strip-mined areas in the Eastern States include alfalfa, white clover, crimson clover, birdsfoot trefoil, lespedeza, red clover, crownvetch, hairy vetch, kura clover, zigzag clover, and white and yellow sweetclover.

Cheyenne, Wyo.

Schuman, G. E., W. A. Berg, and J. F. Power.
1976. Management of mine wastes in the Western United States. In Land application of waste materials, p. 182-194. Soil Conservation Society of America, Ankeny, Iowa.

The purpose of this paper was to review the literature available on managing mine wastes and relate it to aspects of energy development in the Western United States. Subjects discussed include social impacts, effect of the mining- and power-generating industry on water quality and quantity, problems associated with the reclamation of disturbed lands, and methods of reclaiming these lands. These problems are discussed in relation to oil shale development; other mineral mining also is discussed briefly.

Schuman, G. E., and E. M. Taylor.
1978. Use of mine spoil material to improve topsoil. Wyoming Agricultural Experiment Station Research Journal 130, 11 pp.

The purpose of this study was to determine the effect on plant growth of mixing the topsoil with a good-quality subsoil or spoil material. Subsoil or spoil material was mixed with topsoil at the rate of 0, 25, 50, 75, and 100 percent to determine what levels could be used without harming soil properties and plant growth. Although this paper describes a specific subsoil and spoil, the principles can be extended to other site-specific situations where topsoil resources are limited in quantity or quality.

TECHNOLOGICAL OBJECTIVE 2

Restore disturbed area to optimum level of agricultural productivity or other uses.

Fort Collins, Colo.

Reeder, J. D., and W. A. Berg.
1977. Plant uptake of indigenous and fertilizer nitrogen from a Cretaceous shale and coal mine spoils. Journal of Soil Science Society of America 41:919-921.

Deficiency of plant-available nitrogen (N) is often a limiting factor in the revegetation and maintenance of drastically disturbed lands, such as strip-mined coal spoils. In the development of revegetation and management programs, knowledge is needed of the plant availability of both indigenous N and added fertilizer N in geologic materials disturbed and left as surface or subsurface plant growth media. This research was designed to evaluate the significance to plant growth of mineralization of indigenous N and uptake of added NH_4-N in geologic materials. Plants grown in fresh spoils took up less indigenous N than plants grown in previously vegetated spoil or in soil. Initial plant recovery of fertilizer N from the geologic materials was less available to plants with time than the same amount of fertilizer N added to soil. The high correlations between mineral N content of laboratory-incubated samples and total N uptake by plants grown under greenhouse conditions suggested that laboratory incubation tests could be useful in estimating the plant-available N potentials of certain drastically disturbed lands before extensive revegetation programs.

Beltsville, Md.

Barrows, H. L.
1979. Reclamation of surface-mined areas in the United States. In Proceedings of the international hill lands symposium, pp. 445-456, Morgantown, W. Va., October 1976.

More than one-third of the land area in the United States may be disturbed seriously by man at some time in the future. These disturbances would include mining for minerals and fossil fuels and disturbance by large construction projects. Coal mining is responsible for almost one-half of the disturbed mine land in the United States. This paper provides a national perspective on the coal reserves in the United States and describes the history and growth of surface mining. Environmental problems are described for oil shale and for surface mining for Appalachia and the West. Socioeconomic factors, research, and future needs also are discussed.

Foy, C. D., A. J. Oakes, and J. W. Schwartz.
1979. Adaptation of some introduced *Eragrostis* species to calcareous soil and acid mine spoil. Communications in Soil Science and Plant Analysis 10(6):953-968.

Plant growth is frequently limited by Fe-related chlorosis on calcareous soils and by mineral toxicities on strongly acid soils and mine spoils.

Better adapted varieties are needed for both soil situations, which are not always economically correctable. In a search for such germplasm, 4 species (20 accessions) of lovegrass were grown in greenhouse pots of a calcareous soil at pH 7.3. Two species were also compared on acid mine spoil at pH 3.5 and 4.7.

Species, and accessions within species, differed significantly in tolerance to the calcareous soil, as measured by susceptibility to chlorosis and yield of plant tops.

Chlorosis and poor growth of certain accessions on calcareous soil (pH 7.3) were not explained by specific mineral deficiencies or toxicities. However, the tops of chlorosis-susceptible accessions had lower ratios of Fe/Mn, Fe/Zn, and Fe/Cu than those of chlorosis-resistant accessions. This imbalance is believed to interfere with Fe metabolism in plant tops.

Results suggested that superior strains of lovegrass species can be selected for adaptation to calcareous or acid soils and that certain accessions characterized in these studies can be useful in studying the physiological mechanisms of mineral stress resistance in plants.

Schwartz, J. W., and C. D. Foy.
1979. Response of four grass species to rock phosphate on an acid strip mine spoil. In Proceedings of the international hill lands symposium, pp. 544-548, Morgantown, W. Va., October 1976.

Rock phosphate is discussed as a source of phosphorus for plants on acid strip-mined spoils. The low pH tended to increase the availability of P from the rock phosphate. Acid-tolerant species, such as weeping lovegrass and deer-tongue, were more tolerant than little bluestem or tall fescue to the acid strip-mined spoil.

Mandan, N. Dak.

Bauer, A., P. Nyren, G. Reichman, G. W. Gee, and J. E. Gilley
1978. Fertilization of wheat, corn, and grass-legume mixture grown on reclaimed spoilbanks. North Dakota Agricultural Experiment Station Research Report No. 67, 15 pp.

Soil tests for undisturbed soils to predict deficiency of phosphorus and nitrogen and related corrective measures using commercial fertilizers were evaluated on reclaimed sites with three crops over a 2-year period. Yield response of wheat, corn, and a grass-legume mixture to phosphorus and nitrogen fertilizers confirmed a deficiency or sufficiency of each nutrient. The capability of the soil tests to predict nutrient status was considered suitable for reclaimed sites. The rate of applying nutrients to correct the deficiency, however, may have to be adjusted from the rate utilized for undisturbed sites.

Gilley, J. E., G. W. Gee, A. W. Bauer, W. O. Willis, and R. A. Young.
1976. Infiltration on surface mine sites in western North Dakota. North Dakota Agricultural Experiment Station Farm Research 34(2):32-35.

Water movement into a sandy loam soil at a native range site was considered to be unrestricted. Infiltration was minimal on spoil plots left undisturbed. Although rototilling did not affect water movement into a sandy clay loam spoil, it did affect clay loam and silty clay loam spoil materials. Water movement into these materials was restricted, however, to a depth of less than 6 inches. Water storage on the topsoil sites was limited to the topsoil material. Disking of the topsoil interface had no effect on water movement into the spoil medium.

Hofmann, L., R. E. Ries, J. F. Power, and R. J. Lorenz.
1977. Effects of grazing intensity on vegetation and animal performance on reclaimed strip-mined land. Proceedings of the fifth symposium on surface mining and reclamation, pp. 306-310, Louisville, Ky, October 1977.

Reclaimed strip-mined land in North Dakota is somewhat fragile, and the effects of grazing this land are unknown. To study these effects, duplicated sets of pastures were stocked at 0, 0.6, 1.2, and 1.8 acres/yearling steer to obtain control, heavy, moderate, and light grazing intensities, respectively, on land near Center, N. Dak., that was reclaimed under the State's 1969 reclamation law. A mixture of cool-season grasses and legumes was seeded in 1973 and not harvested before beginning the study in 1976. During 1976, 3,331 pounds/acre dry matter were produced on the ungrazed control and 80, 44, and 32 percent of the forage was grazed at the heavy, moderate, and light grazing intensities, respectively. The 1976 grazing season was 55 days as compared with 30 days in 1977, which had a much drier spring. In 1977, the heavily grazed pasture had significantly less dry matter than the other treatments when grazing was started. When grazing was stopped, no harvestable forage remained on the heavily grazed pasture. Steers on heavily grazed pastures produced average daily gains of 0.9 pound/head as compared with 2.0 pound/head on the moderately and lightly grazed pastures. Beef production in 1977 equaled 49, 52, and 36 pound/acre for the heavily, moderately, and lightly grazed pastures, respectively. These preliminary data indicated that reclaimed mined land should be suitable for grazing, but additional research is needed to establish good grazing management guidelines for reclaimed land.

Hofmann, L., R. E. Ries, J. F. Power, and R. J. Lorenz.
1978. Influence of point frame quadrat orientation on vegetative analyses obtained on disturbed land reseeded in rows. Proceedings of the First International Rangeland Congress, pp. 521-523, Denver, Colo., August 14-18, 1978.

The effects of grazing are being studied upon vegetation and animal performance on rangeland that was disturbed by coal strip mining and reclaimed by seeding in rows. Plant species cover under four grazing intensities was measured by point-frame quadrats that were oriented diagonally, parallel or perpendicular to the seeded row, or randomly located to determine if the orientation had any influence on estimates of vegetation cover. Differences due to quadrat orientation generally were not significant at the 0.05 probability level.

Hofmann, L., R. E. Ries, J. F. Power, and R. J. Lorenz.
1978. Grazing reclaimed strip-mined sites. North Dakota Agricultural Experiment Station Farm Research 36(1):3-5.

Grazing will become an important use for reclaimed strip-mined lands. Little is known about grazing management on these areas or about the effect grazing has on vegetation and soils. A grazing study, initiated in spring 1976, is providing information to determine some of these effects.

Hofmann, L., and R. E. Ries.
1980. Comparison of vegetative composition, cover, and production on reclaimed and nonmined grazed lands. In Proceedings of the symposium on adequate reclamation of mined lands? pp. 27-1 to 27-10, Billings, Mont., March 1980.

Animal performance and vegetative production, composition, and cover data from a grazing study on reclaimed strip-mined land near Center, N. Dak., were compared with similar data obtained on nonmined grazing land. Dry matter yields harvested from moderately, lightly, and ungrazed reclaimed pastures were equal to or better than yields from two adjacent nonmined range sites. Performance of yearling steers, grazing reclaimed pastures at moderate or light intensities, equaled steer performance from nonmined pastures at Mandan, N. Dak., during spring and early summer. Four cool-season, introduced plant species made up about 90 percent of the vegetation on the reclaimed site, and four native species made up over 75 percent of the vegetation on the native sites. Except for ungrazed controls, live plant cover was less on reclaimed land than on native range as measured by foliage hits with a point frame. However, live vegetation plus litter was equal or better on reclaimed sites than on native sites, and cover was sufficient to prevent soil loss on both reclaimed pastures and native range, as predicted by the Universal Soil Loss Equation. If only live-plant basal hits were used to estimate cover, neither the reclaimed nor native sites had sufficient cover to prevent unacceptable soil loss. The reclaimed area had equal or better vegetative production, equal or better cover when live plants plus litter were considered, and equal animal performance; but, in light of rules and regulations proposed for reclamation, the question remains: "Is this area adequately reclaimed?"

Power, J. F., R. E. Ries, F. M. Sandoval, and W. O. Willis.
1975. Factors restricting revegetation of strip-mine spoils. Proceedings of the Fort Union coal field symposium, pp. 336-346. W. F. Clark, editor, Billings, Mont., April 1975, Montana Academy of Science.

To develop technology for reclamation, research was initiated in 1970 to restore productivity to areas subjected to mining in the Fort Union region. Working through facilities of the Northern Great Plains Research Center at Mandan, N. Dak., a team of scientists was assigned to (1) determine characteristic physical and chemical properties of spoils and overburden in the major coal fields in the Fort Union region, (2) evaluate the influence of these properties upon the growth potential of various plant species, and (3) develop reclamation methods whereby mined land can be restored to a level of productivity equal to or exceeding that which existed before mining. These research activities have resulted in publications in which

chacteristic properties of spoils and overburden have been identified at several locations in the Fort Union region.

Power, J. F., R. E. Ries, and F. M. Sandoval.
1976. Use of soil material on spoils--effects of thickness and quality. North Dakota Agricultural Experiment Station Farm Research 34:23-24.

Results of experimentation on returning original soil material to smoothed spoils are discussed in regard to their potential for restoring original productivity. Both the thickness and the quality of soil material spread on spoils affect potential crop yields. On sodic spoils, as little as 2 inches of soil material are highly beneficial, but at least 30 inches of soil seem to be needed for maximum production.

Power, J. F., and O. L. Bennett.
1977. Protection of soil and water resources on land disturbed by mining. Proceedings of the second national conference on energy/environment, Washington, D.C. Decision Series, pp. 195-201, U.S. Environmental Protection Agency 600/9-77-012.

Most recent research results are presented, and their effect is discussed on known reclamation technology and restoration of productivity to mined land. Information is included from both the Eastern and Western United States. This paper reviews research to develop technology to protect the soil and water resources of mined land. In the past decade, great advances have been made in developing the needed reclamation technology. Programs and activities are defining many of the parameters involved and are providing guidelines by which user groups can make decisions. The information acquired is being used in extension and educational programs and by industry in designing reclamation practices, by regulatory agencies in enforcing reclamation legislation, and by advisory groups serving industry and regulatory agencies.

Power, J. F., R. E. Ries, and F. M. Sandoval.
1978. Reclamation of coal-mined land in the Northern Great Plains. Journal of Soil and Water Conservation 33:69-74.

Current knowledge is summarized for problems and techniques on reclaiming mined lands in the Northern Plains. Included is a discussion of available natural resources, water and its limitations, soil fertility, and salinity. Future problems and research needed to overcome these problems also are outlined.

Power, J. F., F. M. Sandoval, and R. E. Ries.
1978. Restoration of productivity to disturbed land in the Northern Great Plains. In The reclamation of disturbed arid lands, pp. 33-49. R. A. Wright, editor. University of New Mexico Press, Albuquerque.

The effects of mining on natural resources in the Northern Great Plains are discussed. The problems associated with conserving these resources are outlined. Research-derived technology that overcomes these problems is described along with foreseeable problems that require intensified research.

Power, J. F., F. M. Sandoval, and R. E. Ries.
1979. Topsoil-subsoil requirement to restore North Dakota mined lands to original productivity. Mining Engineering, December 1979, pp. 1708-1712.

Returning the original soil material to the surface of smoothed mine spoils is a practical means of restoring agricultural productivity. Research has established that high-sodium spoils in North Dakota (1) must be covered with about 70 cm of soil material to achieve maximum production, (2) topsoil must be segregated and spread separately from subsoil, (3) potential production depends on the quality of the soil material returned, and (4) erosion and upward salt movement must be controlled for sustained production. Erosion is best controlled by reducing final grades as much as possible during the smoothing process followed by prompt establishment of vegetation.

Ries, R. E., J. F. Power, and F. M. Sandoval.
1976. Potential use of supplemental irrigation for establishment of revegetation on surface mined lands. North Dakota Agricultural Experiment Station Farm Research 34(2):21-22.

Since almost all postmining land uses--recreation, livestock and wildlife grazing, crop production, and soil protection--depend upon vegetation, irrigation is a potential tool in reestablishing vegetation, especially perennial rangeland vegetation. Continued research will better define the benefits and techniques of supplemental irrigation for the establishment of plants and plant communities on surface-mined land in North Dakota.

Ries, R. E., F. M. Sandoval, J. F. Power, and W. O. Willis.
1976. Perennial forage species response to sodium and magnesium sulfate mine spoils. Proceedings of the fourth symposium on surface mining and reclamation, National Coal Association, pp. 173-183, Louisville, Ky, October 1976.

Magnesium and sodium sulfate are the principal salts in lignite and subbituminous coal spoils originating from the Fort Union geologic group in North Dakota, Montana, and Wyoming. The authors studied the effect of magnesium and sodium sulfates on the growth of eight perennial forage species in growth chambers at three stages of plant development--germination, emergence-establishment, and growth. For the emergence-establishment and growth portions of this study, the salts were applied to mine spoils of two different textures from a mine near Colstrip, Mont. Results showed that plant species responded differently to similar kinds or concentrations of salt and that individual species responded differently to a given salt at different development stages. In general, three types of plant responses were observed: (1) No effect of kind or concentration of salt, (2) sensitive to salt concentration but not to specific kind of salt, and (3) sensitive to both kind and concentration of salt. Growth of some species was affected by soil texture. Results indicate that stands of such species may become established or survive in field plantings only under certain restricted conditions.

Ries, R. E., R. F. Follett, F. M. Sandoval, and J. F. Power.
1978. Planting date and water affect initial establishment of perennial vegetative communities. In International Congress for Energy and the Ecosystem, 15 pp., Grand Forks, N. Dak., June 1978.

Experience and research show water is the most important single factor influencing successful revegetation of disturbed land. Sufficient and timely precipitation is essential for seed germination and seedling establishment. The growth media must be permeable, with good water-holding capacity, to store sufficient available water for plant growth. While the importance of water for successful revegetation is realized, little is known about the specific effect of water on dry matter production, species density, and species composition of establishing vegetative communities.

In 1975, an experiment was initiated to study the effects of precipitation amount and frequency (simulated) and planting date on the establishment of an introduced and a native mixture of perennial forage species. Precipitation plus added water to simulate a wet year (10 percent frequency) increased total plant density for the native mixture and dry matter production seven weeks after seeding for both mixtures. Total plant density was higher for the May planting than for the July planting with natural precipitation, but was higher for July planting under higher simulated precipitation. Dry matter production seven weeks after seeding was lower for the July planting.

Species composition of the mixtures was affected in a few instances by added water or planting date. Natural precipitation plus added water favored blue grama and alfalfa establishment, and July planting reduced annual weed growth.

Ries, R. E., F. M. Sandoval, and J. F. Power.
1978. Re-establishment of grasses on land disturbed by mining in the the Northern Great Plains. In Proceedings of the First International Rangeland Congress, pp. 700-703, Denver, Colo., August 1978.

In this study topsoil replacement was essential to stand establishment and productivity on mine spoil. Fertilizer application increased stand production, but did not influence stand density. Selection of grass species that are readily established is essential to establishing fully stocked initial stands.

Sandoval, F. M., J. J. Bond, J. F. Power, and W. O. Willis.
1973(a). Lignite spoils in the Northern Great Plains--characteristics and potential for reclamation. Proceedings of the first annual research and applied technology symposium on mined-land reclamation, pp. 117-133, Pittsburgh, Pa., March 1973.

Overburden materials left as spoils on the surface after strip-mining for lignite and subbituminous coal in North Dakota, Montana, and Wyoming were studied in the laboratory and field to evaluate the potential of these materials for reclamation and revegetation. Results showed that the physiochemical properties of materials left as spoils provide a very poor

environment for vegetative growth. Materials from the Tongue River and Sentinel Butte formations within the Fort Union group were often extremely fine textured (Montmorillonitic), moderately saline, and highly sodic. Severity of the problems associated with high clay and high adsorbed sodium content increased with depth from the original surface. Low organic matter combined with fine texture enhances the sodium dispersion effect, which makes the spoil materials extremely unstable, highly impermeable, and erodible. The content of available phosphorus in spoil materials was very low. The content of available nitrogen varied considerably, depending on the age of the exposed spoils. Treatments showing promise for reclamation include fertilization (especially with phosphorus) in combination with the use of topsoil, vegetative (straw) mulches, and possibly gypsum as a calcium amendment. The response to gypsum in field studies has been disappointingly slow. Strip mining is accelerating greatly in the Northern Plains; therefore, means must be developed to reduce the textural, sodic, and fertility limitations before desirable perennial plants can survive and grow appreciably under the semiarid climate of the region.

Sandoval, F. M., J. J. Bond, J. F. Power, and W. O. Willis.
1973(b). Lignite mine spoils in the Northern Great Plains--characteristics and potential for reclamation. _In_ Some environmental aspects of strip-mining in North Dakota. North Dakota Geological Survey Series No. 5, pp. 1-24. North Dakota Geological Survey, Grand Forks, N. Dak.

This paper is similar to the preceding one. It provides information on the physical and chemical properties of lignite spoils, pointing out consequent problems in reclamation.

<u>University Park, Pa.</u>

Pedersen, T., A. S. Rogowski, and R. Pennock, Jr.
1978. Comparison of morphological and chemical characteristics of some soils and minesoils. Reclamation Review 1:143-156.

Investigations were conducted to compare changes in soil morphology and chemistry before and after surface coal mining and reclamation operations in Clearfield County, Pa. Four minesoil pits located within a disturbed area and four natural soil pits located in adjacent undisturbed areas were described and sampled. The minesoils were classified as Udorthents, three of the natural soils were classified as Typic Dystrochrepts and one as an Aquic Fragiudult. The most prominent feature of the minesoils was their high degree of coarseness and high rock fragment content; their roots tended to concentrate along soil coarse fragment interfaces. In general, the chemical constituents of the minesoils were similar to those of the natural soils. However, as a result of extended weathering, more total bases have been leached from the natural soils and significantly more extractable aluminum was found in them than in the minesoils. The high content of carboniferous shale and coal fragments in the minesoils affected organic carbon and nitrogen determinations, while comparison of mineralogy suggested that the minesoils studied were derived from the same materials from which the natural soils had originally developed.

Pedersen, T. A., A.S. Rogowski, and R. Pennock, Jr.
1980. Physical characteristics of some minesoils. Journal of Soil Science Society of America 44:321-328.

Studies were conducted to evaluate physical properties of spoils resulting from surface-coal mining and reclamation operations in Clearfield County, Pa. Bulk density, evapotranspiration, water retention, infiltration, and hydraulic conductivity values were determined at 10 sites randomly located within a 4-hectare experimental area. Average bulk density of the surface 0.5 m layer of minesoil was 1,763 kg/m3 while specific surface at most sites averaged 31 m^2/g. Microlysimeter data indicated that evapotranspiration (ET) on minesoil could be approximated by class-A pan evaporation or by model results. A large amount of spatial variation was observed in infiltration, water retention, and hydraulic conductivity values. In the uppermost 0.75 m of the profile, most minesoils on the average retained 35 mm of water, between 10 and 1,500 kPa, compared to 136 mm for the adjoining soils. When water was available ET approached potential; however, hydraulic properties of the minesoil would likely lead to droughty conditions and extended periods of plant stress.

Rogowski, A. S.
1979. Evapotranspiration process in strip mine spoil. Paper No, 79-2005. 1979 Summer meeting of the American Society of Agricultural Engineers, and the Canadian Society of Agricultural Engineers, Winnipeg, Canada, June 24-27, 1979.

Evapotranspiration on spoil reclaimed to ryegrass was about 2 mm/day and 40 percent of incoming precipitation seeped below a 0.3 m root zone. Utilizing kriging, aerial distributions of ET are given and spoil balance is approximated by a model. The data can be represented by a two parameter equation $ET = St^{0.5} + At$; however, values of S and A appear highly variable.

Blacksburg, Va.

Jones, J. N., Jr., W. H. Armiger, and O. L. Bennett.
1979. Specialty crops, an alternate land use on surface mine spoil. In Proceedings of the international hill lands symposium, pp. 560-564, Morgantown, W. Va., October 1976.

Following stabilization and conservation practices in reclamation of surface spoil, additional land use through rotations to high-value specialty crops offers diversification and a chance to increase food production in Appalachia. Field experiments with sweet corn, bush beans, and tomatoes were conducted on a surface mine bench area near Beckley, W. Va. Stabilization cover of Ky 31 fescue and sericea lespedeza was plowed down before seedbed preparation. Soil amendment variables for the corn and beans included lime rates and three levels of fertility. For the tomatoes, lime was broadcast to bring the pH to 6.5-6.8. Evaluated mulches included straw and sawdust. Mulch significantly influenced the uptake of 12 elements in tomato leaf tissue, as compared with fertilizer. For sweet corn, the trend reversed--straw mulch influenced uptake of five elements, and fertilizer influenced seven elements.

In the bean study, sawdust influenced the uptake of nitrogen, iron, and aluminum, with potassium being significant as a primary fertilizer element. Highest tomato fruit yield was 11 tons/acre from sawdust mulch and 300 pounds/acre of fertilizer nitrogen. Marketable ears of sweet corn weighed 5,500 pounds/acre and were produced with straw mulch and the high lime and fertilizer treatment. The highest horticultural shelled bean yield was 3,850 pounds/acre, which was produced with sawdust mulch and high fertility. From this preliminary research, good management plus the addition of adequate primary nutrients and mulch apparently are required for satisfactory vegetable growth. Yield data indicated that alternate uses of mine soil offer a challenging potential.

Morgantown, W. Va.

O. L. Bennett.
1975. Forage production and quality from disturbed land areas. Proceedings of the West Virginia chapter, and West Virginia Grassland Council, pp. 19-35, Soil Science Society of America, Blackwater Falls State Park, Davis, W. Va., September 1975. West Virginia University Press, Morgantown, W. Va.

Several forage species grown on low-pH, strip-mined spoils in the Eastern United States were used to determine the yield potential and forage quality from disturbed land areas. Good yields have been obtained with many forage species that are adapted to acid soils, and forage quality is similar to that normally found on most soils in the Appalachian region. In general, forage quality represented general nutritional conditions of the soil area on which the forage was grown. All forages were high enough in quality to maintain grazing beef animals. Forage quality sometimes was not good enough, however, to support lactating dairy cows. Additional work is needed before forage quality can be verified under all conditions. When forages were grown on extremely acid-mine spoil areas, metal content sometimes was elevated high enough to be of concern for grazing animals. This is especially true of lead.

Bennett, O. L.
1977. Potential for reclamation and revegetation of Eastern strip-mine spoils. Proceedings of the third international conference on environmental problems of the extractive industries, pp. 10.5.1-10.5.9, Dayton, Ohio, November 1977. R. F. Rolston and P. S. Sweeny, ed. Wright Company, Kettering, Ohio.

This paper gives summaries of surface mining for coal in the Eastern United States and the potentials and problems for reclamation. Specifically emphasized are controls on surface mining by the 1977 U.S. Federal Strip Mine law, reclamation guidelines, and research accomplishments. Specific topics include provisions of the Federal strip mine law, environmental problems, chemical and physical limitations in reclamation, adaptation of plant species, use of domestic and industrial waste materials, and research problems.

Bennett, O. L.
1977. Strip mining--new solutions to an old but growing problem. Crops and Soils 12-14, January 1977.

On acid spoils, lime and a complete fertilizer usually are needed for seeding establishment and plant growth. Usually, only a complete fertilizer is required on limestone spoils. In the Eastern United States, a major research objective has been to screen grasses and legumes for possible use on acid strip-mined areas that contain toxic levels of soluble aluminum and manganese.

In addition to providing an economical, quick ground cover, forages help restore the spoil material to a productive soil. Both the chemical and physical properties of the spoil matertial are changed significantly within a relatively short time. In West Virginia, the organic matter in a strip-mined spoil was increased from 0.2 to 2.0 percent, and the pH in the top 8 inches of soil was increased from 3.8 to as much as 5.9 within 4 years. In addition, the water-holding capacity of the soil increased from about 3 percent to more than 14 percent.

Crops tested include most of the agriculturally important grass and legume species; such horticultural species as blueberries, apples, peaches, grapes, potatoes, tomatoes, sweet corn, and such specialty crops as buckwheat, crambe, and kenaf. The economics of using a specific crop will be determined by accessibility, soil pH, fertility, and other plant growth factors.

Bennett, O. L.
1978. Mining, strip. In McGraw Hill Yearbook of Science Technology, pp. 301-303. McGraw-Hill Book Company, Inc., New York.

Research is being pursued with a number of legume and grass species for hay and pasture production. Research with adapted tree species indicates that many can be used successfully on acid spoils. A number of plant species considered as specialty crops can be grown on strip-mined spoils.

Research is in progress to find ways of establishing a quick vegetative cover on the steep slopes of strip-mined areas to stabilize them against erosion, subsidence, and slides. This research involves a complete chemical and physical analysis of the spoil material to determine lime and fertilizer requirements. In general, grasses and legumes are recommended for quickly stabilizing steep outer slopes against soil erosion. A mulch generally is required to stabilize the soil until plants become established.

Bennett, O. L., E. L. Mathias, W. H. Armiger, and J. N. Jones, Jr.
1978. Plant materials and their requirements for growth in humid regions. Proceedings of the symposium on reclamation of drastically disturbed lands, pp. 285-305. Frank W. Schaller and Paul Sutton, editors. Wooster, Ohio, August 1976. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison, Wis.

Disturbed land areas need to be revegetated as quickly as possible to avoid serious erosion problems. A wide range of plant species can be used on disturbed land areas if the specific growth requirements of these plants are met. This chapter deals with the more desirable species and their adaptation to disturbed lands in the Eastern United States. Annual and perennial forage or aesthetic values are discussed, along with such other features as acid tolerance and drought resistance. Cereal grains also offer a quick cover and later can be used as a mulch or nurse crop for permanent grasses and legume species.

Lundberg, P. E., O. L. Bennett, and E. L. Mathias.
1977. Tolerance of bermudagrass selections to acidity. I. Effects of lime on plant growth and mine spoil material. Agronomy Journal 69(6):913-916.

Nonfertile acid soils, including many strip-mined spoils, are common in the Appalachian region of the United States. Since strip-mined spoils often have low water-holding capacity, no soil structure, and various toxic materials, correction of pH and fertility problems may not be economical. Studies are warranted, however, involving judicious use of lime, fertilizer, and suitable plant species.

The objective of this research was to study the growth of several bermudagrass selections on strip-mined spoil treated with various rates of lime. Three cultivars and five strains of bermudagrass were planted in 1-quart pots filled with low-pH mine spoil (pH 2.9) treated with six rates of calcitic lime from 1 to 6 tons/acre (1.3 to 7.8 g/pot). All pots were given blanket applications of nitrogen, phosphorus, potassium, and magnesium as need was determined from soil analyses. Four harvests were made at about 6-week intervals. Oven-dry weights of both forage and roots were determined at the end of the study. All eight selections showed a significant increase in mean root and forage yields at lime rates of up to 3 tons/acre. Higher lime rates did not increase forage yields and lowered root yields. Selections differed markedly in their growth response to various lime levels. 'Tufcote' outyielded all other selections at the 1 ton of lime/acre rate, but its highest yield was lower than that of any other selection. The 'P.I. 315904' and 'Native I' varieties grew best over the range of all lime treatments. Soils in which the various selections had grown differed significantly in pH and residual available nutrients. Bermudagrass tolerated very acidic conditions (pH 3.4). That yield increased most dramatically through the first three rates, even though pH increased little, may indicate that the toxicity of certain elements rather than the low pH limits bermudagrass growth. This study indicated that 'Tufcote' is a good choice if pH was as low as 3.4; however, at a nearly optimum pH of 4.5, 'P.I. 315904' or 'Native I' is much better.

<u>Cheyenne, Wyo.</u>

Lang, R., F. Rauzi, W. Seamands, and G. Howard.
1975. Guidelines for seeding range pasture and disturbed lands. Wyoming Agricultural Experiment Station Bulletin No. 621,11 pp.

The bulletin is a general guide for seeding dryland range, pasture, and disturbed land sites in Wyoming. It was written by specialists in plant and soil research in the area. The guidelines list essential cultural practices for plant establishment in Wyoming, under arid or semiarid conditions and a short, cool, growing season. Seeding recommendations and practices are discussed by rainfall zones of 5 to 9 inches, 10 to 14 inches, and above 15 inches of precipitation.

Species and varieties of forages and woody plants are recommended and discussed for special situations and uses. Adaptable woody plants (trees and shrubs), listed under extended trials at the Cheyenne Horticultural Field Station, are given for disturbed land reclamation use.

Mason, M. L., D. L. Evans, G. E. Schuman, and G. M. Passini.
1980. Standing stubble versus crimped straw mulch for establishing grass on mined land. In Proceedings of the symposium on adequate reclamation of mined lands? pp. 21-1 to 21-13, Billings, Mont., March 1980.

The use of straw, standing stubble, and cther organic mulches on newly seeded reclaimed areas are common practices used to minimize soil erosion and aid in seedling establishment. Three treatments were evaluated for their effectiveness in giving soil protection, suitability for seedling stablishment, and treatment cost. The small grain standing stubble gave the longest lasting protection against soil erosion. Crimped straw was applied at the rate of 2.2 tons/acre and was reduced by 53 percent in seven months because of wind. Seedling establishment was 5.4 and 4.8 plants/foot of transect for the stubble and crimped straw treatments, respectively. The stubble treatment showed less temperature fluctuation at the shallow soil depths and a greater cumulative water infiltration than did the crimped straw. Compared to crimped straw (or hay), the cost of establishing a standing stubble was only 5 to 25 percent as high, with much less chance of a major weed infestation. In a separate study, the use of feedlot compost gave very poor results with respect to soil erosion and seedling establishment. Moreover, the cost of feedlot compost as a mulch was prohibitive on a large scale.

Schuman, G. E., and J. F. Power.
1980. Plant growth as affected by topsoil depth and quality on mined lands. In Proceedings of the symposium on adequate reclamation of mined lands? pp. 6-1 to 6-9, Billings, Mont., March 1980.

The question of topsoil depth requirements on mined lands may be site specific. The amount of topsoil available in most cases is the limiting factor. The quality of spoil material to be covered by topsoil is also a controlling factor. Topsoil has many benefits including increasing infiltration, improving rooting media for plant establishment, enhancing nutrient cycling, and serving as a source of seed, rhizomes, and root cuttings that can promote in species diversity of the vegetative cover. Topsoil replacement is also required by law and aids in the success of revegetation.

Schuman, G. E., E. M. Taylor, Jr., F. Rauzi, and G. S. Howard. 1980. Standing stubble versus crimped straw mulch for establishing on mined lands. Journal of Soil and Water Conservation 35:25-27.

Small grain stubble seeded in the spring and a grass mixture fall-seeded into that stubble has advantages over use of crimped straw or hay residue as a mulch for wind and water erosion control on mined land. Small grain stubble gives longer lasting protection because it is not susceptible to being blown out. Five metric tons of straw per hectare was crimped in October; only 47 percent of that residue remained in April. In contrast, 94 percent of the stubble residue remained for the same period. Seedling establishment was 54 plants and 48.6 plants per 3.05-meter transect for the stubble and crimped residue treatments, respectively. Stubble resulted in less temperature fluctuation at shallow soil depths; it also produced a 25-percent greater cumulative water infiltration than did the crimped straw. Compared with crimped straw or hay, costs of the stubble residue treatment were 75 to 95 percent lower. Chances of major weed infestation are also lower.

Laramie, Wyo.

Rauzi, F., and R. L. Tresler. 1978. A preliminary report on herbage yields, stand evaluation, soils, chemical content of selected grasses and a legume grown on topsoil, White River and Wind River geologic materials. Wyoming Agricultural Experiment Station Research Journal No. 124, 21 pp.

During April 1972, native and introduced grasses and cicer milkvetch were seeded on areas that were either topsoiled or covered with geologic material (spoil) from the Wind River or White River formations. The purpose of the study was to determine which species were best adapted and to determine their response when planted directly into spoil material as compared with topsoil. This study showed the value and necessity of using topsoil for successful revegetation and maintenance of that vegetation on disturbed lands, even though the overburden material has good physical and chemical characteristics. When grown on spoil material, the yields and plant population gradually decrease and require more intensive management.

TECHNOLOGICAL OBJECTIVE 3

Stabilize disturbed areas against erosion, subsidence, and slides.

Fort Collins, Colo.

Gilley, J. E.
1980. Runoff and erosion from mined lands in western North Dakota. In Proceedings of the symposium on the adequate reclamation of mined lands? pp. 5-1 to 5-18, Billings, Mont., March 1980.

Erosion and runoff, resulting from natural and artificial rainfall, were measured from treatments representing premined, mined, and postmined conditions. Measured soil losses from simulated rainfall were greatest on bare topsoil plots and least on a noncultivated rangeland site. Application of a straw mulch on a topsoil plot reduced erosion from artificial rainfall by 66 percent. Soil loss from snowmelt runoff on rangeland, spoil and topsoil plots was found to be minimal. The erosion potential of a recently topsoiled site significantly decreased as vegetation became reestablished. Results indicate the need for suitable management practices on bare topsoil materials to maintain erosion and runoff losses within acceptable tolerances.

Peterson, R. J.
1977. Laboratory simulation of soil erosion. M.S. Thesis. Colorado State University, Department of Civil Engineering, Fort Collins, Colo.

The design, construction, and calibration of a physical model to study soil erosion phenomena are described in this thesis.

Rainfall was simulated by capillary tubing drop formers inserted in rectangular plastic reservoirs on a 1-inch grid. The velocity of the drops at impact with the soil surface approached 77 percent of their terminal velocity. A mechanism is described to increase drop energy dispersion over the surface. The drops were applied uniformly over a 41-foot-long, 4-foot-wide flume with slope adjustable between 0 and 3.33 percent. Intensity was controlled by varying the pressure in the reservoir system. The stage graph was traced with a water level recorder in a trapezoidal flume.

The soil used for the first erosion study was a sandy loam, placed at a 5-inch depth above the flume base. A porous ceramic candle assembly introduced line sources of suction at the soil base and was used to study soil moisture effects. System calibration included measurements of the intensity and distribution of the rain and drop size. An initial experiment determined that suction within the soil mass has no measureable effect on sediment erosion yield, using a 4-inch/hour intensity applied for 1 hour at a 3.33 percent slope.

Beltsville, Md.

Armiger, W. H., J. N. Jones, Jr., O. L. Bennett, F. L. Bagley, G. E. Griebel.
1979. Revegetation of steep outer slopes for erosion control in strip-mined area. In Proceedings of the international hill lands symposium, pp. 529-534, Morgantown, W. Va., October 1976.

Erosion of the steep outer slopes and acid spoil materials are the main obstacles in establishing vegetative cover on surface-mined spoils in Appalachia. A technique is discussed to establish persistent vegetation on the steep outer slopes. Right after the spoil is regraded, the prepared seedbed should be stabilized and a ground cover should be established. Delays cause sheet erosion and then permanent deep gullies. The construction of lateral grooves about 2 feet apart down the slope, on the contour and parallel to the main bench area, will help retain the fertilizer and seed during germination. Infiltration of water and available soil moisture for plant growth also are improved. Two acid strip mine sites in West Virginia--Mountain and Bolt Mountain--were prepared for revegetation using the lateral groove technique. At both locations, experiments were conducted comparing rock phosphate with superphosphate as spoil amendments. Birdsfoot trefoil and crownvetch were the primary species evaluated; however, weeping lovegrass was overseeded to help provide a quick cover for stabilization. Direct seeding was compared with transplanted clones and found to be just as effective in establishing a vegetative cover. Dry matter yield produced by additions of 9 metric tons per hectare of rock phosphate was comparable to that produced by 290 kilograms of superphosphate plus lime.

Mandan, N. Dak.

Gee, G. W., J. E. Gilley, and A. Bauer.
1976. Use of soil properties to estimate soil loss by water erosion on surface mined lands of western North Dakota. North Dakota Agricultural Experiment Station Farm Research 34(2):40-43.

Soil losses up to 118 tons per acre from a sandy loam topsoil are predicted for first-year conditions on steep slopes (17 percent) on reshaped mine land. Cultural practices can reduce this amount. Seeding the area into permanent pasture is advisable, but soil losses would still be high during the initial year of establishment. Reducing the slope optimizes land use and minimizes soil losses during the initial establishment and subsequent stabilization of the mined land.

Gee, G. W., A. Bauer, and R. S. Decker.
1978. Physical analyses of overburden materials and mine land soils. In Reclamation of drastically disturbed lands, F. W. Schaller and Paul Sutton, editors, pp. 665-686, American Society of Agronomy, Crop Science Society of America, and Soil Conservation Society of America, Madison.

Soil-water storage, water availability, surface erosion, and land stability are physical processes altered by mining. Methods of evaluating these changes were investigated.

Gilley, J. E., G. W. Gee, and A. Bauer.
1976. Runoff and erosion from snowmelt on surface mine sites in western North Dakota. North Dakota Research Report No. 62, 10 pp.

Runoff averaged 41 percent for rangeland, 48 percent for spoil, and 71 percent of snow water equivalent for topsoil plots. Soil loss averaged 0.04 ton for the rangeland, 1.92 tons for the spoil, and 0.38 ton for topsoil plots. Increasing the slope on sandy clay loam from 4.8 to 17.6 percent increased erosion 0.99 to 2.86 tons per acre. Soil content of runoff was greatest near the end of the snowmelt period.

Gilley, J. E., G. W. Gee, and A. Bauer.
1976. Particle size distribution of eroded materials on surface mine sites in western North Dakota. North Dakota Agricultural Experiment Station Farm Research 34(2):35-36.

The particle size distribution of spoil materials eroded from nontilled plots corresponded closely to surface conditions preceding rainfall. Tillage, however, caused substantial changes in particle size distribution of eroded material. The particle size distribution of sediment did not change significantly in successive samples collected during a storm.

Gilley, J. E., G. W. Gee, A. Bauer, W. O. Willis, and R. A. Young.
1977. Runoff and erosion characteristics of surface mined sites in western North Dakota. Transactions of the American Society of Agricultural Engineers 20:697-700.

A rainfall simulator was used to measure runoff and erosion from rangeland, spoil, and topsoil sites. Soil losses were greatest on bare topsoil plots and were least on the noncultivated rangeland site. Application of a straw mulch reduced erosion on topsoil by over 90 percent. However, erosion and runoff from the mulched topsoil sites were still more than 50 percent higher than erosion and runoff from the rangeland site.

University Park, Pa.

Rogowski, A. S.
1979. Development of erosion pavement in stripmine spoil. 1979 Winter meeting of the American Society of Agricultural Engineers, Paper No. 79-2538. New Orleans, December 11-14, 1979.

Spoil, topsoiled spoil and natural soil were subjected to simulated rain. Large erosion losses occurred on the natural soil; largest piping losses occurred on the spoil. Infiltration was a major flow pathway on spoil; runoff predominated on the soil and topsoiled spoil. Settling was more localized on the natural soil, while armouring, largest on the spoil, appeared to be a random phenomenon.

Jones, J. N., Jr., W. H. Armiger, and G. C. Hungate.
1973. Seed ledges improve stabilization of outer slopes on mine spoil. Proceedings of the symposium on research and applied technology on mined-land reclamation, National Coal Association, Pittsburgh, Pa., pp. 250-258.

Stabilization against erosion of outer slopes in surface-mined mountainous terrain continues to be a complex problem. Long, steep slopes should be broken, but the excessive cost plus insufficient land area makes this impractical. A miniature terrace system provided stairstep ledges on the contour for holding seed, fertilizer, and water. Microclimate for germination and growth also improved. Results of a 2-year study on revegetation of steep slopes using stairstep terraces were reported for two mountain sites in southern West Virginia. Treatments evaluated included three rates of rock phosphate compared with superphospate. Main plots were divided so that one-half of each plot was established from seed and the other half was established from transplanted seedlings. Special-purpose legumes, birdsfoot trefoil, and crownvetch were the basic species; however, plots were overseeded with weeping lovegrass to help provide a quick cover for stabilization.

A sketch of a proposed concept for an outer slope seed ledge machine is shown along with suggested modifications for conventional construction equipment.

Jones, J. N., Jr., W. H. Armiger, and O. L. Bennett.
1975. A two-step system for revegetation of surface mine spoils. Journal of Environmental Quality 4(2):233-235.

Establishment of persistent vegetation on surface-mined spoils depends on fertility and pH management, adapted species, seeding methods, mulch, and soil water conditions. A two-step procedure was tested. First, a fast-growing cereal grain was established to minimize erosion and provide ground cover. It was killed chemically to provide an *in situ* mulch for establishment of persistent grasses and legumes of acceptable quality for pasturage or hay. Lime and fertilizer were surface broadcast into the killed rye in May. Selected forage legumes were broadcast seeded alone and with a companion grass. Germination and seedling growth were excellent. Over a 3-year period herbage yields from red clovers averaged 2,680 pounds/acre and, when seeded with a companion grass, the yield increased to 3,930 pounds/acre. White clovers averaged 1,700 pounds/acre when seeded alone and 2,680 pounds/acre when seeded with companion grasses. Highest yield in the third year was from crownvetch at 5,350 pounds/acre.

Most of the soil erodes during the first few months after surface mining before permanent soil cover is established. By using fast-growing grass species, such as cereal grains or summer annuals, the disturbed land areas can be stabilized quickly and the vegetative growth from these species can later serve as mulch for interseeding permanent grasses and legumes. This management system differs from nurse crop seeding in that the cereal grain

or summer annual does not compete with the permanent grass-legume seedlings for moisture.

Morgantown, W. Va.

Bennett, O. L., J. N. Jones, Jr., W. H. Armiger, and P. E. Lundberg.
1972. New techniques for revegetation of strip-mined areas. Proceedings of the twenty-seventh annual meeting of the Soil Conservation Society of America, Portland, Ore., pp. 50-55.

Vegetative cover should be established on all strip-mined land as soon as possible after final grading. Soil amendments and special techniques for revegetation of low-pH mine spoils are discussed. The use of raw-rock phosphate on low-pH spoils helped promote growth of grasses and legumes. Excellent growth was obtained with Midland and Tufcote bermudagrasses and with weeping lovegrass at low-pH with rock phosphate and a complete fertilizer. Several acid-tolerant plant species were evaluated for use on low-pH spoil. The most promising included bermudagrasses, weeping lovegrass, tall fescue, bluestem, indiangrass, switchgrass, redtop, deer tongue, and bentgrass.

Small-grain crops (rye, wheat, barley) were used successfully to establish a quick cover and provide a mulch for interseeded permanent grasses and legumes. Stairstep-seed ledges proved very successful for establishing plant cover to reduce erosion on steep outer slopes. Use of molybdenum and lime was studied for establishment of legumes. A small amount of molybdenum was used successfully for several legume species instead of larger amounts of lime. Other work was reported in which acid-tolerant rhizobium strains were selected for legumes on low-pH spoil. Other techniques for revegetating toxic spoils include use of domestic and industrial materials, such as sewage sludge, garbage mulch, and fly ash. Boron toxicity and composted garbage seem very useful for reclamation.

Bennett, O. L. Vegetation to heal scars.
1973. In Plants, animals and man. Proceedings of the twenty-eight annual meeting of the Soil Conservation Society of America, Hot Springs, Ark., October 3, 1973, pp. 249-253.

Research was centered around problems associated with establishment of adapted grasses and legumes on low-pH, strip-mined spoil areas. Although the final plant species desired on some strip-mined areas may be forest species, such herbaceous species as grasses and legumes should be planted first to stabilize these highly erodible materials. Analyses of spoil materials determined the soil amendments needed to establish vegetative cover. These included soil pH, lime requirement, and available calcium, magnesium, phosphorus, and potassium. In many cases it was necessary to determine concentrations of such problem elements, such as iron, aluminum, manganese, and the amount of soil amendment such as lime or rock phosphate, needed to overcome toxic concentrations of these elements for plant growth.

Another approach was to screen grasses and legumes for possible use on strip-mined spoils that were tolerant to high concentrations of aluminum

and manganese. In all, more than two dozen grass and legume species were tested for their adaptation to low-pH strip-mined conditions. If the fertility and management needs of a particular species are met, almost any grass species can be grown on strip-mined areas.

Vegetative cover should be established as quickly as possible after the spoil has been graded to final form to prevent severe erosion and pollution from sedimentation. Under such conditions, small grains and summer annual species, such as millet and sudangrass, may provide the rapid cover necessary to prevent runoff and later provide a good mulching material for interseeding more permanent grasses and legumes.

Bennett, O. L.
1978. Conservation (chapter 16). In Tall fescue, R. C. Buckner and L. P. Bush, editors. American Society of Agronomy Monogram Series, 44 pp.

Recent research has identified several plant species adapted to the environmental conditions generally found on disturbed land areas. Tall fescue, either alone or in combination with other grasses and legumes, is used widely for stabilization of disturbed land areas throughout the United States and in other parts of the world. Excellent results have been obtained using relatively small rates for lime and fertilizer on strip-mined spoils with a pH of 4.0 and above. To prevent severe erosion and pollution from sedimentation, tall fescue should be seeded, either alone or with other grasses and legumes, as quickly as possible after mine spoils or disturbed areas have been graded to final form.

TECHNOLOGICAL OBJECTIVE 4

Prevent surface and ground water degradation in and adjacent to disturbed land areas.

Fort Collins, Colo.

Gardner, H. R.
1978. Hydrologic and climatic factors. Proceedings of the symposium on reclamation of drastically disturbed lands, pp. 173-190, Wooster, Ohio, August 9-12, 1976. American Society of Agronomy, Crop Science Society of America, and Soil Conservation Society of America.

This chapter considers aspects of hydrology important in the reclamation of drastically disturbed lands. Components of the hydrological cycle on the macroscale are described to illustrate the physical basis of modifying the hydrologic regime by disturbance and reclamation activities. Precipitation and temperature are components that have little opportunity for control but have a large effect on reclamation. Infiltration is the component that exerts the greatest control on the hydrology of an area. Some of the physical characteristics affecting infiltration are slope, surface texture and roughness, and compaction. Freeze-thaw action also has an effect, particularly where the spoil is exposed to the surface. Stream base flow may be increased or decreased with a corresponding change in peak flows, depending on the differences found in the water conduction characteristics of the disturbed layer. The transport of chemicals within the ground water probably will increase after disturbance. The amount of change depends on the material and on the change in the ground water movement.

Gardner, H. R.
1980. Estimation of salt load from spoil material based on drill samples. In Proceedings of the symposium on the adequate reclamation of mined lands? pp. 4-1 to 4-7, Billings, Mont., August 1980.

Separation of spoil material into size fractions, and establishing curves of electrical conductivity versus water leached for each fraction are shown to provide reasonable data for use in constructing a curve of salt leached versus water used for a spoil with any particle-size distribution. This curve construction is done by weighing the results from the curves for the various size fractions and summing the results from these fractions. It is shown that greater than 95 percent of all the salts leached are obtained from the particle-size fraction less than 0.5 mm in diameter. On this basis, the estimation of salt leaching from spoil can be based on the contribution of this fraction neglecting anything obtained from larger material. A simplified vacuum extraction technique to obtain leaching curves is presented upon which a routine procedure could be based.

Reeder, J. D., and W. A. Berg.
1977. Nitrogen mineralization and nitrification in a Cretaceous shale and coal mine spoils. Journal of Soil Science Society of America 41:922-927.

Deficiency of plant-available nitrogen (N) is often a limiting factor in the revegetation and maintenance of disturbed lands, such as strip-mined coal spoils. Although they are usually deficient in available N, the total N content of spoils can be comparable to the total N content of local undisturbed soils. However, our understanding is limited of N cycling in disturbed geologic strata. Therefore, an incubation study was undertaken to determine mineralization rates of indigenous N and nitrification rates of added N_4-N in Cretaceous coal spoils. Net N mineralization rates of indigenous N were generally slower in spoils than in topsoil since a smaller proportion of the total N in geologic materials is potentially mineralizable. A higher level of N mineralization activity was found in vegetated spoils as compared with nonvegetated spoils.

The results of these preliminary studies indicated that N mineralization rates and N mineralization potentials gradually will approach those in soils. Future studies are needed, however, to analyze and quantify the effects of vegetation and physical and chemical weathering of geologic materials n N mineralization rates.

Smith, R. E.
1977. Field test of a distributed watershed erosion/sedimentation model. In Soil erosion: Prediction and control. Proceedings of the national conference on soil erosion, pp. 201-209, Soil Science Society of America, Ankeny, Iowa.

Assuming that accurate prediction of watershed sediment production depends on more accurate hydraulic modeling, an advanced watershed model equipped with a sediment simulation component is required. The initial evaluation of such a model on a 3-acre rangeland watershed demonstrated the ability to predict both hydraulic watershed response and sediment delivery with a small error. Weaknesses shown by this initial comparison included some error in sediment rates from secondary rainfall and a demonstration of the futility of accurately measuring sediment production by use of ponding structures.

Smith, R. E., and D. A. Woolhiser.
1978. Some applications of hydrologic simulation models for design of surface mine topography. In The reclamation of disturbed lands, pp. 189-196, R. A. Wright, editor. Proceedings of the annual meeting of the American Association for the Advancement of Science, Denver, Colo., February 1977.

With the legal requirements and time constraints on reclamation efforts, hydrologic models can be used in evaluating various reclamation treatments. Empirical data used in the Universal Soil Loss Equation provide guidelines for topographic design, but reclamation problems often will vary considerably from the conditions for which this equation has proved useful. More detailed investigations are needed to establish both parameters for hydraulic erosion rates on a range of soil and physical relations between soil properties and erosion susceptibilities. The hydrologic effects of increasing density of cover must be quantified so that the time required to reach a "stable" or legally reclaimed watershed may be estimated more easily.

Present capability in rainfall simulation is adequate for constructing sequences of statistically representative precipitation for simulation and for comparing the hydraulic response of various possible topographic treatments. For reclaimed areas, the dynamic changes and interrelations of erosion, plant establishment, and surface hydraulics offer the greatest challenge to hydrology.

Woolhiser, D. A., and K. G. Renard.
1978. Stochastic aspects of watershed sediment yield. Proceedings of the specialty conference on verification of mathematical and physical models in hydraulic engineering, pp. 561-567, College Park, Md., August 9-11, 1978.

The conclusion from this study was that stochastic models of sediment yield have important application in design of dams, debris basins, and other hydraulic structures. The approaches used in developing stochastic sediment yield models range from detailed, physically based models with distribution functions obtained by sampling from Monte Carlo simulations to empirical, event-based models for which distribution functions of sediment yield can often be obtained analytically. The best approach for any particular application depends greatly on the available data as well as the size of the watershed.

Woolhiser, D. A., and G. G. S. Pegram.
1979. Maximum likelihood estimation of Fourier coefficients to describe seasonal variations of parameters in stochastic daily precipitation models. Journal of Applied Meteorology 18(1):34-42.

Maximum-likelihood estimations of Fourier series are convenient expressions for the seasonally fluctuating values of parameters in stochastic models of precipitation. Least-squares methods often are used to estimate the Fourier series coefficients, but this method has two important disadvantages. First, the "data" points are, in fact, estimates of parameters, and they may have unequal variances and should not be given equal weight because of varying sample size. Second, there is no statistically sound procedure to test the significance of individual harmonics.

In this paper, the authors investigated methods of obtaining maximum-likelihood estimates of the Fourier coefficients to describe the seasonal variability in the parameters for a stochastic rainfall model. Parameters were obtained from a two-state Markov chain model for wet- and dry-day occurrence and from a mixed exponential model for distribution of depth on wet days.

The procedure was demonstrated on four sample stations scattered across the continental United States. A constrained multivariate optimization scheme and a simple univariate procedure were used for maximum-likelihood estimation, and these schemes were compared with a least-squares estimate. The two seasonally varying parameters for the Markov chain are mutually independent, but the Fourier coefficients for each parameter are weakly dependent. The three seasonally varying parameters in the mixed exponential distribution are mutually dependent. For the four precipitation records analyzed, however, acceptable results could be obtained by simultaneously

estimating the constant series terms and then independently estimating the harmonic amplitudes and phase angles. A likelihood ratio test can be used to test the significance of each added harmonic. This analysis also showed that the significant Fourier coefficients can be plotted on maps as isopleths, providing a concise description of regional precipitation climatology.

Mandan, N. Dak.

Gee, G. W.
1976. Calculated versus measured _in situ_ hydraulic conductivities. Journal of Soil Science Society of America 40:969-970.

This article discusses the major difficulties of using the Green and Corey method for calculating hydraulic conductivities in a general application.

Gilley, J. E., G. W. Gee, and A. Bauer.
1976. Water quality of impoundments on surface-mined sites. North Dakota Agricultural Experiment Station Farm Research 34(2):37-39.

Concentrations of water-soluble constituents varied between sampling locations. Values of some chemical parameters were higher in water from the recently established impoundments, whereas values of other constituents were higher at older sites. Surface water quality changed significantly between November 14, 1975 and May 13, 1976. The authors recommend that chemical characteristics of an impoundment be determined before it is used as a livestock or irrigation supply.

Gilley, J. E., G. W. Gee, and A. Bauer.
1977. Effect of tillage on water movement into surface-mined materials. North Dakota Agricultural Experiment Station Farm Research 34(2): 37-39.

Disking the spoil interface of high sodium adsorption ratio before topsoil placement increased the depth of water penetration into the spoil by about 3 inches. No significant difference appeared in water storage between nontilled and moldboard-plowed spoil materials. The underlying spoil on both the tilled and nontilled treatments greatly restricted downward water movement.

Power, J. F., Bond, J. J., Sandoval, F. M., and Willis, W. O.
1974. Nitrification in Paleocene shale. Science 183:1077-1079.

Exchangeable ammonium nitrogen is present in Paleocene (Fort Union) shale below a depth of 33 feet in North Dakota and eastern Montana. Above 33 feet, exchangeable ammonium nitrogen is nitrified _in situ_. The lack of viable nitrifying organisms and the probable lack of oxygen prevent _in situ_ nitrification below 33 feet. Shale samples incubated at 27°C under non-sterile conditions and those exposed to atmospheric contamination showed active nitrification without additional treatment.

Coshocton, Ohio

Hamon, W. R., Faz Haghiri, and D. Knochenmus.
1977. Research on the hydrology and water quality of watersheds subjected to surface mining. In Proceedings of the fifth symposium on surface mining and reclamation, pp. 37-40, National Coal Association, Coal Conference and Exposition IV, October 1977.

This paper describes research in a 5-year cooperative research program in southeastern Ohio, which involves four watersheds that will be mined, each for a different coal seam, and a benchmark watershed with 35 years of hydrologic data that will not be mined. Objectives are to:

a) Obtain complete hydrologic and water quality data from the watersheds before, during and after mining, and from erosion and treatment plots;

b) Characterize the study watersheds and plots, and obtain chemical and physical data for the soils and overburden materials before surface mining, and for replaced topsoil and underlying spoil materials after mining;

c) Describe the hydrogeology of the watersheds and the water-quality characteristics of the aquifer system for pre- and post-mining conditions, and apply a ground-water, chemical transport model;

d) Develop a computer model for simulation of the surface hydrologic and water quality regimes, including sediment transport, for both pre- and post-mined conditions; and,

e) Determine costs to obtain the necessary chemical, physical, and hydrologic data as required for surface mining permits, and perform an economic evaluation of various degrees of control of runoff, sediment and water quality.

Hamon, W. R., J. V. Bonta, Faz Haghiri, and J. Helgesen.
1979. Research on the hydrology and water quality of watersheds subjected to surface mining. I. Premining hydrologic and water quality conditions. In Proceedings of the symposium on surface coal mining and reclamation. National Coal Association, Coal Conference and Exposition V, pp. 70-98, Louisville, Ky., October 1979.

Five watersheds, ranging in size from 29 to 49 acres, were selected in east-central Ohio to investigate the hydrology and water quality conditions before, during, and after surface mining. Four of the watersheds will be surface-mined, and one will be undisturbed and used as a control. Such a selection was made because the different natural and mined geologic profiles would reflect in different soils, surface- and ground-water flow regimes, and water quality.

Field equipment was installed to obtain runoff, weather, and soil moisture and ground water data, and to collect runoff and precipitation samples. Baseline data were also collected on soils, vegetation, and geology. Using the county and State soil legends, a total of 26 different soils were delineated on the four watersheds scheduled for surface mining. Delineations on each watershed were differentiated on the basis of the soil series along with percent slope and degree of erosion.

Vegetation surveys were made on each of the study watersheds in their unmined condition. These data were translated into generalized maps of the major overstory vegetation types, basal area of vegetation, and the vegetation surrounding soil moisture access tubes. All the study watersheds during the study period differed from the long-term averages by -8 to +19 percent. The deepest snow measured was 11.5 inches in January 1976; a measurement was 8 inches in February 1976. Spring flows were nearly constant for short periods of time and ceased at two sites in the fall. Maximum average daily flow rates ranged from 0.0052 cfs.

Runoff for the control watershed was erratic during the comparable year of 1977, with a yearly excess of 3 percent above normal. The proportion of precipitation occurring as surface runoff on the study watersheds ranged from 8 to 35 percent. Peak discharges observed for the period ranged from 5.86 to 81.95 cfs. Runoff from the small watersheds was rather low, ranging from less than 1 to only 4 percent of the precipitation. Runoff from the control watershed was observed under stable conditions from 1967 through 1977, with a 3-year break in the record from July 1972 through June 1975. This record should prove invaluable in modeling the hydrologic behavior of the study watershed for the unmined condition. Storm-runoff water, base-flow, and ground water samples from four of the unmined watersheds were collected and analyzed quantitatively for 39 water quality parameters. Monthly precipitation samples were analyzed for 22 parameters. The average concentrations of the surface water quality parameters for the unmined watersheds, except for suspended solids, were as low or lower than the EPA recommended maximum allowable concentrations in drinking water. Several parameters in precipitation equaled or exceeded the levels of corresponding parameters in runoff water. Iron ranged from an average of less than 3 to 228 ug/l. The average concentrations of suspended solids in runoff ranged from 118 to 1,110 mg/l for the watersheds. For base flow, concentrations ranged from 44 to 247 mg/l.

Chemical quality of ground water varied considerably between and within watersheds. Much of the shallowest ground water was of calcium bicarbonate type; deeper water was of diverse water types and generally more mineralized. Dissolved-solids concentration was commonly within the range of 200 to 600mg/l, and pH ranged from 6.5 to 8.0.

A one-dimensional unsaturated model was developed for interfacing with a quasi-three-dimensional ground-water model as part of a projected composite hydrologic model. The unsaturated flow model includes provisions for an evapotranspiration model.

University Park, Pa.

Pionke, H. B., A. S. Rogowski, and C. A. Montgomery.
1978. Percolate quality of strip mine spoil. American Society of Agricultural Engineers, Paper No. 78-2581, Chicago.

Large caissons, filled with a reconstructed spoil stratigraphy, were used to simultaneously determine the water-transport and water-quality properties of a Pennsylvania coal strip-mined spoil. The caissons had lysimeters at selected depths and were leached periodically with rainwater. The results include pH, total acidity, total soluble iron, calcium, magnesium, manganese, aluminum, and sulphate. The total acidity of percolates approximated the total acidity of the spoil layer extract and pyrite content of corresponding spoil strata.

Pionke, H. B., and A. S. Rogowski
1979. How effective is deep placement of acid spoil? Proceedings of the symposium of the Canadian Land Reclamation Association, pp. 87-104, Regina, Saskatchewan, Canada, August 13-15, 1979.

There are basically two problems associated with deep burial of acid spoil materials: First is chemical; the second is hydrologic. The objective of deep placement is to prevent pyritic oxidation to sulfuric acid and associated salts by restricting the supply of oxygen. If, however, during the mining, handling, and reclamation operations, the pyrite in spoil becomes partly weathered, deep placement may actually increase the rate of acid and salt leaching. Hydrologically speaking, deep placement is aided at preventing the percolation water or rising water table to come in contact with acid spoil materials. It is difficult and expensive to make a completely impervious envelope around deeply placed spoil. Establishment of perched water tables and internal piping may lead to rapid percolation of surface water through acid materials. Reestablishment of regional water tables may take many years to complete. Yet, such rising water table may leach the acid and salts already present, especially when the spoils become seasonally covered with water and ultimately result in acid mine drainage.

This paper is addressed to the selected chemical and hydrologic processes within the spoil that control the leaching rate below and above the water table, and investigates possible water flow pathways and alternative reclamation procedures, such as topsoiling and establishment of good vegetative cover.

Rogowski, A. S.
1977. Acid generation within a spoil profile: Preliminary experimental results. Proceedings of the seventh symposium on coal mine drainage, National Coal Association, Coal Conference, October 18-20, 1977, Louisville, Ky., pp. 25-40.

Preliminary results after initial water application to two caissons filled with mine spoil showed a much higher infiltration rate and settling on spoil alone than on spoil covered with soil. Considerable piping and internal erosion tended to transport large amounts of soil material deep into spoil profiles. Temperature profiles reflected water movement. The

oxygen concentration values decreased when soil covered the spoil surface. Determination of organic carbon in spoil materials using conventional methods seemed questionable. Although sulfur contents within a spoil profile undoubtedly were related to acid generation, the highest sulfur content (acid shale, caisson 2) did not seem to generate exceptionally high acid effluent. Apparently, adequate topsoil cover (caisson 1) improved the quality of the water reaching the water table. Possibly, piping and erosion could have created an internal filter.

The results suggested that under controlled field conditions a similar filter may form. Since topsoil cover seemed to substantially reduce oxygen diffusion, less oxidation and acid generation with depth might be expected on soil reclaimed, according to a new Pennsylvania law. The study results showed that organic carbon and leaching analyses of individual layers might not truly reflect the field situation. Organic carbon may often be contaminated with coal or organic shale fragments, whereas a cumulative profile effluent seemed to contain considerably higher concentration of salts than combined leachates from the individual layers.

Rogowski, A. S., H. B. Pionke, and J. G. Broyan.
1977. Modeling the impact of strip mining and reclamation processes on quality and quantity of water in mined areas: A review. Journal of Environmental Quality 6(3):237-244.

Current literature contains numerous studies of acid generation, neutralization, and transformation in strip-mined spoil materials, yet the rate-determining processes on the field scale are not well understood. Even less seems to be known about the spoil waterflow, oxygen, diffusion, surface runoff, erosion, evapotranspiration, and temperature distribution within the spoil banks. Most spoils seem to be considered principally from the standpoint of rapid revegetation, use of amendments, and favorable placement of acid-producing materials. These authors concluded that hydrology of the spoil system could be simulated using standard modeling techniques. They also state that experimentally obtained temperature oxygen distribution patterns probably could delineate acid-producing areas, assuming that pyrite is not limiting and is distributed evenly through the zone of interest.

Rogowski, A. S., and E. L. Jacoby, Jr.
1979. Monitoring water movement through strip mine spoil profiles. Transactions of the American Society of Agricultural Engineers 22(1):104-198, and 114.

Two large caissons were used to measure water movement in a reconstituted spoil profile. This paper presents the details of instrumentation, and the authors propose methods for determining the spoil-water-retentivity curve and the hydraulic conductivity as a function of water content and the tensiometer pressure, including a correction for coarse fragment content. This correction may be significant when modeling flows in spoil materials. During water application, water infiltrated faster on spoil alone and less of it was retained in the profile after drainage than on topsoiled spoil.

More sediment moved with infiltrating water in the topsoiled profile, and oxygen concentrations after application of water were lower than on spoil alone. Similar situations may prevail in the field. During the initial wetting, settlement was considerable and changes in temperature and bulk density were good indicators of water movement within the spoil and topsoiled spoil profiles. However, flow through larger channels did contribute significant amounts of water to the water table in the spoil without being detected by radioactive probes, temperature probes, or tensiometers.

Rogowski, A. S.
1980. Hydrologic parameter distribution on a mine spoil. 1980 Watershed management symposium, pp. 1-17, American Society of Civil Engineering, Irrigation and Drainage Division, Boise, Idaho. July 2-23, 1980.

Large and small rings were used in the field to measure sorptivity (S) and A-values in Philip's (1957) infiltation equation. Attempts were made to analyze the structure of experimental dictributions using the theory of regionalized variable and to compare these distributions with the results obtained by Sharma, et. al. (1980) on an Oklahoma soil. Contours of infiltration and parameters S and A were compared with the profile water contours and water table elevations. Structure of these distributions was also analyzed. The small rings were likely to vary more spatially and temporally than the large ones. The correlation between S and A-values was poor, and the interpretation of processes and properties measured was constrained by the small area. The parameters S and A varied uniformly within a 20-m diameter neighborhood; for larger distances, semivariograms of these properties seemed to be either random or to slowly increase linearly. Semivariograms of water table elevations reached a constant value within a 100-m range. Those for moisture characteristic were linear, whereas those for profile water content suggested nested structure with variability increasing with depth. The predicted infiltration pattern and its parameters S and A showed little apparent relationship to the profile water content distribution, the water table elevations, or the observed changes in time of either.

Morgantown, W. Va.

Strohl, J. H., and J. L. Hern.
1976. Removal of undesirable cations from acid mine water by a new cation change material. West Virginia University Bulletin Series No. 2-2, 14 pp.

This study was directed toward the development of materials and methods useful for removing metal-ion pollutants from water. Several modified graphites were prepared that had ion-exchange or chelating properties capable of removing iron, nickel, cobalt, magnesium, and calcium from water, The absorption capacities of these modified graphites were too low for economical use in water treatment. They are useful for analytical separations, however. Attempts at producing materials with higher absorption capacities were unsuccessful. Adjustment of pH and removal of some metal ions or the hydroxides by the electrogeneration of base seem to be a practical process for large-scale water treatment.

TECHNOLOGICAL OBJECTIVE 5

Utilize waste material in reclaiming disturbed areas.

Peoria, Ill.

Blessin, C. W., and W. J. Garcia.
1977. Heavy metals in the food chain by translocation to crops grown on sludge-treated strip-mine land. Symposium on municipal wastewater and sludge recycling on forest land and disturbed land, Philadelphia. March 21-23, 1977, Paper No. 39, pp. 471-482, The Pennsylvania State University Press.

Improved wet-ashing procedures were developed to obtain information on levels of heavy metals in corn grown under normal agronomic conditions. Concentrations of zinc, manganese, copper, lead, cadmium, and chromium were established by flame atomic absorption in commercial whole-kernel dent corn samples originating in six Midwestern States. A nonflame technique was used to measure mercury concentrations. The same seven heavy metals were studied in corn grown on strip-mined spoil treated with anaerobically digested liquid sludge applied at a rate of 25 tons of sludge solids per acre. For comparison, an adjacent plot was not treated with sludge. Grain, cobs, and husks generally showed an increasing order of concentration of heavy metals. Corn grain grown on untreated and on sludge-treated soils did not differ significantly in heavy metal content from 11 corn varieties grown normally.

Research was extended to examine a variety of consumer-oriented corn products including milled fractions, prepared breakfast and snack foods, syrups, and oil. Metal content of corn-based foods depended primarily on whether the germ was present in the finished product. Products with the lowest metal content were syrups and oil. When the total amount and variety of food eaten daily are considered, corn products contribute minor quantities of naturally occurring lead, cadmium, and mercury to the diet.

Garcia, W. J., C. W. Blessin, G. E. Inglett, and R. O. Carlson.
1974. Physical-chemical characteristics and heavy metal content of corn grown on sludge-treated strip mine soil. Journal of Agricultural Food Chemistry 22(5):810-815.

Corn was grown on a strip-mined soil where anaerobically digested liquid sludge had been applied at a rate of 25 tons of sludge solids per acre. An adjacent plot received no sludge. Corn grain grown on untreated strip-mined soil was characterized as immature, and kernel size varied from small to intermediate with about 20 percent of the kernels being diseased. In contrast, the sludge-treated corn was well developed and yield was four times higher than that of the untreated corn. Furthermore, a significant protein enhancement of 2.5 percentage points was also realized.

Concentrations of seven heavy metals (zinc, manganese, copper, lead, chromium, cadmium, and mercury) increased in grain, cobs, and husks in that order. For corn grain grown on untreated and sludge-treated soils, essentially no significant differences were found in heavy metal content when

compared with 11 other corn varieties grown normally. Heavy metal contents of both soil and sludge samples also were determined.

Garcia, W. J., C. W. Blessin, H. O. Sandford, and G. E. Inglett. 1979. Translocation and accumulation of seven heavy metals in tissues of corn plants grown on sludge-treated strip-mined soil. Journal of Agricultural Food Chemistry 27:1088-1094.

Metal translocation studies for Zn, Mn, Cu, Pb, and Hg were conducted for corn plants grown on strip-mined soil amended with anaerobically digested sewage sludge. Differential metal accumulation rates in the seven tissues analyzed showed that generally the highest metal concentrations occur in the leaves and roots and the lowest in the grain and cob. With the exception of Mn and Hg, metal concentrations increased in tissues as a result of sludge application. The greatest increases were for Cd where mean tissue concentrations (ppm) for unamended and sludge-grown conditions, respectively, were roots: 0.062, 3.63; lower stems: 0.027, 0.204; and leaves: 0.276, 1.52. Metal extractabilities for plant uptake were established for the soil samples adhering directly to the root system of the corn plants studied; these extractabilities were than compared to metal concentrations in the leaf and root tissues.

Ithaca, N.Y.

Welch, R. M., W. A. House, and D. R. Van Campen. 1978. Availability of cadmium from lettuce leaves and cadmium sulfate to rats. Nutrition Reports International 17(1):35-42.

Cadmium toxicity in man and animals is well documented, but little is known about the bioavailability of cadmium occurring in plants. Zinc has been shown to be antagonistic toward cadmium toxicity in some biological systems. Lettuce was grown in solution culture containing either 0.045 or 0.225 ppm of cadmium labeled with ^{109}Cd, and either 0.131 or 0.654 ppm zinc. The lettuce produced reflected (1) low cadmium, low zinc; (2) low cadmium, high zinc; (3) high cadmium, low zinc; and (4) high cadmium, high zinc treatments. Both zinc-adequate and zinc-depleted rats were fed single doses of either ^{109}Cd-labeled cadmium sulfate or ^{109}Cd-labeled lettuce leaves. After rats were fed a basal diet for 6 days, food was withheld for 16 hours before the experimental diets were fed. The experimental diets were fed 5 hours and then replaced with the basal diet. All rats were assayed for ^{109}Cd in a "whole body" gamma spectrophotometer. The assay was repeated at 24- to 48-hour intervals for 12 days. The retention and absorption of ^{109}Cd by the rat were determined from these data.

Increasing the supply of either zinc or cadmium to plants increased the zinc or cadmium concentration, respectively, in tops. Increasing zinc decreased cadmium in the lettuce growing on the higher but not lower cadmium treatments. Zinc-depleted rats fed low zinc lettuce absorbed more ^{109}Cd than rats fed cadmium sulfate. The percentage of ^{109}Cd absorbed indicated that the cadmium in lettuce leaves of plants grown in the high cadmium-low zinc solution was more available than from the other

treatments. When lettuce contained relatively high levels of both cadmium and zinc, the availability of ^{109}Cd to zinc-depleted rats decreased markedly. Supplying zinc to plants growing in high-cadmium soils may reduce cadmium concentrations in plants, and it may decrease the bioavailability of plant cadmium to animals.

Welch, R. M., and W. A. House
1980. Absorption of radiocadmium and radioselenium by rats fed intrinsically and extrinsically labeled lettuce leaves. Nutrition Reports International 21:135-145.

This study assessed the bioavailability of cadmium and selenium in lettuce leaves fed to male, zinc-depleted rats. Leaves were harvested after 68 days of growth from plants that were supplied varying levels of cadmium and selenium in nutrient solutions. Leaves labeled either intrinsically or extrinsically with ^{109}Cd and ^{75}Se were fed in a single meal to rats. Depending on the meal, absorption of the dose ranged from about 2 to 8 percent for ^{109}Cd and from about 26 to 40 percent for ^{75}Se. Adsorption of ^{109}Cd increased with increased selenium level in the meal, particularly in rats fed intrinsicallay labeled leaves. Neither the source of ^{109}Cd nor the selenium level in the meal affected the biological half-life of ^{109}Cd. Absorption of ^{75}Se decreased with increased cadmium level in the meal. The biological half-life of ^{75}Se was longer in rats fed intrinsically labeled leaves than in those fed extrinsically labeled leaves.

Morgantown, W. Va.

Bennett, O. L.
1971. Grasses and legumes for revegetation of strip-mined areas. Proceedings of the symposium on revegetation and economic use of surface-mined land and mine refuse, Pipestem State Park, W. Va., December 2-4, 1971. D. W. Bondurant, editor. West Virginia University Press.

This article outlines an intensive research program for revegetating and reclaiming acid mine spoils in Appalachia. Studies include chemical and physical evaluation of spoil, greenhouse growth chamber and field studies to evaluate spoil amendments, and field studies to evaluate plant species. Promising spoil treatments include raw rock phosphates, lime, and such organic wastes as sewage sludge and garbage compost. Grass species that were successful on low-pH spoil include bermudagrasses, weeping lovegrass tall fescue, indiangrass, switchgrass, redtop, deer tongue, and bentgrass. Midland and Tufcote bermudagrass varieties were established on pH 3.2 spoil using raw rock phosphate, and a complete fertilizer legume species listed included birdsfoot trefoil, Sericea lespedeza, crownvetch, white clovers, red clover, and several annual lespedezas. Birdsfoot trefoil and crownvetch have performed well on low-pH spoils when nutrient requirements were met. Kudzu has shown promise as a plant cover for high wall areas and outer slopes. Many plant species can be grown successfully on acid strip-mined spoil if the plant nutrient requirements are supplied.

Bennett, O. L., W. H. Armiger, and J. N. Jones, Jr.
1976. Revegetation and use of eastern surface mine spoils. In Land application of waste materials, ch. 13, pp. 195-215. Soil Science Society of America, Ankeny, Iowa.

The use of soil amendments for stabilization and crop production is discussed, and a chemical analysis of the spoil material is described to determine the need for essential elements for plant growth. Such waste materials as digested sewage sludge, composted garbage, and fly ash also were evaluated as soil amendments for mine spoils. Mulches are needed on most heterogenous spoil materials to help alter the surface microclimate and to conserve soil moisture during seedling establishment. Organic mulches, chemical binders, and in situ mulches are discussed.

In the Eastern United States the main objective has been to screen grasses and legumes for possible use on surface-mined areas. Species adaptation for stabilization, persistence, economic importance, and production is discussed along with results from various species under different fertilizer and management practices. The use of perennials, special purpose legumes, and annuals is evaluated in various experiments using a range of establishment techniques and seeding practices. Hydroseeding has been used almost universally in revegetation of surface-mined lands, but aerial and agricultural equipment can be used successfully. The advantages of each must be weighed. Most important is the preparation of a good seedbed, which provides a loose, fresh condition with a rough surface having contoured, corrugated depressions to improve microclimate. Shortcuts generally become costly as omissions in either physical or chemical seedbed parameters. Problems caused by erosion are minimized by using conservation procedures and techniques to improve the physical seedbed and enhance moisture relations and nutrient uptake.

Bennett, O. L., W. L. Stout, J. L. Hern, and R. C. Sidle.
1977. Proceedings of the third international conference of environmental problems of the extractable industries, pp. 10.5.1-10.5.8 Dayton, Ohio, November 1977.

Potential agricultural uses are discussed of fluidized bed combustion waste in agriculture. A detailed chemical and physical evaluation of the material is included, followed by extensive greenhouse, growth chamber, and field studies. Several studies compared application rates of fluidized bed combustion (FBC) waste with conventional lime and sulfur sources using selected crops and soils. The crops used were tall fescue, orchardgrass, red clover, white clover, alfalfa, seedling peach, apple and pecan trees, swiss chard, cabbage, soybeans, tomatoes, sweet corn and field corn. Other studies involved rates of FBC waste and agricultural lime in combinations with various domestic and industrial organic waste material on both agricultural soils and strip-mined spoils. Studies on low-pH strip-mined spoils showed that the FBC significantly increased soil pH and increased yields of sweetclover and buckwheat but that it was inferior to agricultural lime at equivalent rates. Studies were conducted on a low-pH, strip-mined spoil near Morgantown, W. Va., to compare the effect of FBC waste alone and in combination with composted garbage on yields of tall

fescue. Fescue established within plots using garbage compost and FBC waste was comparable to that established using garbage compost and lime.

Mathias, E. L., O. L. Bennett, and P. E. Lundberg.
1977. Use of sewage sludge to establish tall fescue on strip mine spoils in West Virginia. Proceedings of the symposium on municipal wastewater and sludge recycling of forest land and disturbed land. March 21-23, 1977, Philadelphia. The Pennsylvania State University Press.

Yield and mineral concentration of Ky-31 tall fescue were studied for a 3-year period on a low-pH, strip-mined spoil area treated with lime, sewage sludge, and composted garbage. Treatments consisted of 0, 50, and 100 tons/acre of sewage sludge; 0 and 5 tons/acre of lime; and 0 and 10 tons/acre of garbage, each being incorporated into the spoil before seeding. Yield was increased most by the sewage sludge. Lime increased yield substantially but affected it less when applied in conjunction with sludge. Results from garbage application were not consistent--yield increased in some cases.

Forage composition of manganese, chromium, copper, aluminum, iron, and beryllium decreased, whereas cadmium increased on plots that received sludge. Forage composition of some metals was influenced more by sampling date than by treatment. Both lime and sewage sludge increased soil pH and calcium. Soil P was increased by sludge but varied with lime. Available magnesium was increased by sludge treatments but not by lime. Neither lime nor sludge was effective in increasing available potassium. Application of garbage usually had little effect on soil macronutrients.

S. N. Haye, D. J. Horvath, O. L. Bennett, and R. Singh.
1978. A model of seasonal increase of lead in a food chain. A symposium. D. D. Hemphill, editor. University of Missouri, Columbia. Reprinted from Trace substances in environmental health-IX, 1975.

Sewage sludges that are being applied to agricultural land may contain some metals at ore grade concentrations. This study was prompted by concern that food chain lead levels would be enhanced through recycling programs because of the high levels of lead in sludge. Preliminary studies indicated that the application of sludge containing about 500 to 1,000 ppm lead, on dry matter basis, to acidic strip-mined spoils did not increase the lead levels in forages during the season of active growth. Presumably, this was partly because sludge plus lime had raised soil pH. Further studies showed that the highest levels of lead in forages produced on control or sludge-treated plots occurred during the dormant season. Since winter grazing of standing fescue forages is an accepted practice in beef cow-calf production, an animal model was created using voles to study the extent of this seasonal entry of lead into the food chain. The addition of sewage sludge containing up to 1,000 ppm lead to a stand of fescue on an acidic mine spoil bank did not appreciably increase tall fescue forage lead values. Regardless of treatment, a tenfold greater lead level was found in standing forage in winter as compared with summer forage. In these experiments, feeding weanling voles 30 days on rations containing 40 percent of these seasonally different forages led to greater lead values in hard and soft

tissues, and to lower hemoglobin and hematocrit in those fed the winter forage.

W. L. Stout, O. L. Bennett, and E. L. Mathias.
1978. Effects of sewage sludge, garbage mulch, and lime on some chemical and physical properties of a strip mine spoil. Proceedings of the international congress on energy and the ecosystems, Grand Forks, N. Dak., June 12-16, 1978.

The purpose of this study was to identify and quantify the extent of physical and chemical changes in the surface (12 in depth) of a low-pH, surface-mined area that had been revegetated by using sewage sludge, lime, and composted garbage mulch. The chemical data indicated that the effects of revegetation treatments were confined to the top 3 inches of the mine spoil except for possibly calcium and some neutralizing material. The observation that the root mass was confined largely to the top 3 inches also indicated that these roots proliferated at lower depths only in voids along the surfaces of coarse fragments. This proliferation may have been in response to nutrients or moisture illuviating into these voids from overlying layers. Low infiltration rates indicated that there is very little water moving through the spoil profile to extend the effects of treatment to lower depths.

R. C. Sidle, W. L. Stout, J. L. Hern, and O. L. Bennett.
1979. Solute movement from fluidized bed combustion waste in acid soil and mine spoil columns. Journal of Environmental Quality 8(2): 236-241.

Fluidized bed combustion (FBC) waste, a byproduct from a specialized coal-fired power plant, was used as a liming source in a study to determine its impact on solute transport in the soil. The upper 4 inches of acid soil and strip-mined spoil columns (244 in total depth) were treated with enough FCB waste to raise the pH of the two media to 5.0 and 6.0 and 4.6 and 6.0, respectively. Loadings of calcium, sulphur, and magnesium in the upper 4 inches of the pH of 60 mine spoil treatment were 1,132, 309, and 46 ppm soil, respectively. Approximately twice the loadings of these constituents were applied to the upper 4 inches of the acid soil columns. Heavy metal loading rates were very low in all treatments. Columns were leached with 4 inches of water at 10-day intervals for 7 and 14 weeks. Percolate samples collected from mine spoil columns treated with FBC showed no evidence of enhanced levels of aluminum, boron, calcium, cadmium, chromium, fluorine, copper, iron, magnesium, manganese, nickel, phosphate, sulphate, strontium, and zinc after 14 leachings. Acid soil columns, which contained higher levels of organic matter, had percolate concentrations of calcium, magnesium, manganese, and sulphate that increased with increasing FCB waste liming applications. None of the analyzed constituents showed any evidence of downward migration in mine spoil matrix, and only Ca moved downward into the 4 to 6 inches depth of the soil matrix.

TECHNOLOGICAL OBJECTIVE 6

Improve scenic, wildlife, and aesthetic values of disturbed areas.

University Park, Pa.

Rogowski, A. S.
1978. Water regime in strip mine spoil. Proceedings of the symposium on surface mining and fish/wildlife needs in Eastern United States, pp. 137-145, Morgantown, W. Va., December 3-5, 1978. West Virginia University, and Fish and Wildlife Service, U.S. Department of the Interior.

Water movement is described in topsoiled and nontopsoiled, reconstituted, 3-m-deep spoil profiles derived from rocks of the Allegheny series in Pennsylvania. Coarse fragments and sand constituted more than 85 percent of these spoils, and their particle density values resembled those of the overburden. Spoils studied retained 10 to 20 percent of water by volume, one-half to one-third of which was retained as a water film on coarse fragments. At saturation, most of the water could be stored in spoil profiles; however, 30 to 80 percent drained readily. In topsoiled profile, unsaturated flow resulted when water moved from the fine-grained soil into underlying spoil. This impeding action of topsoil layer may lead to better water retention, and greater water availability to plants near the spoil surface. On nontopsoiled spoils, water drained freely, often causing droughty conditions. Once the infiltrating water reached the water table, rate of rise in the water table greatly exceeded the rate of water application because of the spoil's low porosity. When water application ceased, the rate of drainage to the water table resembled the evaporation rate. Topsoiling spoil reduced evaporation losses as compared with those from undisturbed soil profiles.

Cheyenne, Wyo.

Howard, G. S., G. E. Schuman, and F. Rauzi.
1977. Growth of selected plants on Wyoming surface-mined soils and fly ash. Journal of Range Management 30(4):306-310.

Topsoil and overburden were collected randomly at coal mine sites in Gillette and Hanna, Wyo., and at the uranium mine in Shirley Basin, Wyo. Studies of plant growth in greenhouses were conducted on the soil materials in various combinations. Amendments using commercial fertilizer, fly ash, sludge, and manure were tested on grasses, alfalfa, and woody shrubs. Forage plants grown on the soil materials benefited from the addition of nitrogen and phosphorus. The addition of sludge or manure also greatly accelerated growth. Five woody shrubs adaptable to semiarid conditions responded significantly to nitrogen fertilizer. Winterfat and fourwing saltbush showed a species response. The study indicated that mixtures of coal fly ash can be revegetated successfully under controlled conditions. Western wheatgrass on a 1:3:3 mixture of fly ash-sewage sludge-soil showed outstanding growth when water and temperature were not limiting. In these studies, there was no indication of the presence of elements detrimental to plant growth in the soil materials collected from any of the test sites.

Howard, G. S., and M. J. Samuel.
1979. The value of fresh-stripped topsoil as a source of useful plants for surface mine revegetation. Journal of Range Management 32(1): 76-77.

Topsoil from nearby undisturbed areas was stripped and laid directly over regraded overburden to a depth of about 20 cm at Kemmerer, Wyo., and Oak Creek, Colo. Native plant response was determined after two growing seasons with only natural precipitation. Rhizomatous species were the most valuable for establishing the perennial plants. Plant density averaged 4.16 and 1.77 plants/m^2 at Kemmerer, Wyo., Oak Creek, Colo., sites, respectively, but the density was too low to meet State and Federal revegetation standards without additional seeding. Plants established from fresh-stripped topsoil are a plus in revegetation as compared with stockpiled topsoil where these plants are lost.

Howard, G. S,, F. Rauzi, and G. E. Schuman.
1979. Woody plant trials at six mine reclamation sites in Wyoming and Colorado. U.S. Department of Agriculture Production Research Report No. 177, 14 pp.

Select, hardy, and adaptable woody plant clones were propagated vegetatively. A higher percentage of softwood than hardwood cuttings rooted. Intermittent mist and rooting hormones were used on the cuttings. After 2 or 3 years, transplants of 85 woody and 2 forb species, at five surface-mined reclamation sites in Wyo., and one in Colo., showed high survival percentages except at Kemmerer and Hanna, Wyo. None was irrigated.

The study showed that woody shrub plantings may survive a wide range of climatological and soil conditions, but that growth of most species was slow and hindered by wildlife use. Antelope were particularly destructive of the test plants at the Shirley basin and Hanna sites. Species showing the least amount of browse by antelope were silver sagebrush, fourwing saltbush, Maximowicz peashrub, pygmy peashrub, Siberian salt-tree, Chinese wolfberry, matrimonyvine, and trumpet gooseberry.

Schuman, G. E., and G. S. Howard.
1978. Artemisia vulgaris L.: An ornamental plant for disturbed land reclamation. Journal of Range Management 31(5):392-393.

Mugwort wormwood, a herbaceous ornamental sage, shows promise in the reclamation of disturbed lands. Dryland plantings at several mine sites showed excellent survival and growth. Analysis of plant material showed good nutritional quality for domestic livestock and wildlife. Wildlife use of the plantings has been heavy, but it has not affected the plant's survival. Mugwort wormwood can be grown for seed production without serious harvest problems; thus, seed availability would not be a problem as it is with the native woody sages.

Appendix

Table 1. Common and scientific names of plants experimentally tested for their potential importance in strip-mine reclamation

Common Name	Scientific Name
Alfalfa	*Medicago sativa*
alkaligrass, Nuttail	*Puccinellia nuttelliana*
amorpha, Indigo	*Amorpha fruiticosa*
annual ryegrass, Italian	*Lolium multiflorum*
Apple	*Malus sylvestris*
ash, Green	*Fraxinus pennsylvanica*
Barley	*Hordeum vulgare*
Bean	*Phaseolus vulgarus*
Bentgrass	*Agrostis tenuis*
Bermudagrass	*Cynodon dacylon*
Blueberry	*Vaccinium corymbosum*
bluegrass, Kentucky	*Poa pratensis*
bluestem, Big	*Andropogon gerardi*
bluestem, Little	*A. scoparius*
bromegrass, Smooth	*Bromus inermis*
buckthorn, Common	*Rhamnus catharlica*
(1/)	*R. chlorophora*
buckthorn, Dahurian	*R. davurica*
buckthorn, Dyers	*R. tinctoria*
buckthorn, Persianberry	*R. infectoria*
Buckwheat	*Fagopyrum sagittum*
Buffaloberry	*Shepherdia argentea*
canarygrass, Reed	*Phalaris arundinacea*
cedar, Eastern red	*Juniperus virginiana*
cherry, Nanking	*Prunus tomentosa*
cherry, Prinsepia	*Prinsepia sinensis*
cinquefoil, Bush	*Potentialla fruticosa*
cinquefoil, Farrer	*P. farreri*
clover, Crimson	*Trifolium incarnatum*
clover, Kura	*T. ambiguum*
clover, Red	*T. pratense*
clover, White	*T. repens*
clover, Zigzag	*T. medium*
Corn	*Zea mays*
cotoneaster, Brickberry	*Cotoneaster tomentosa*
cotoneaster, Peking	*C. acutifolia*
(1/)	*C. multiflora*
(1/)	*C. obtusa*
(1/)	*C. racemiflora var. desfontainesii*
cottonwood, Narrowleaf	*Populus augustifolia*
Crambe	*Crambe abyssinica*
cranberry, Highbush	*Viburnum burejaeticum*

1/ No acceptable common name.

Common Name	Scientific Name
Crownvetch	*Coronilla varia*
current, Clove	*Ribes odoratum*
cypress, Prostrate summer	*Kochia prostrada*
Deertongue	*Panicum clandestinum*
elm, Siberian	*Ulmus pumila*
falsespirea, Starry ural	*Sobaria sorbifolia var. stellipila*
fescue, Hard	*Festuca ovina var. duriuscula*
fescue, Red	*F. rubra*
fescue, Tall	*F. arundenacea*
Flatpea	*Lathyrus sylvestris*
foxtail, Creeping	*Alopecurus arundinaceus*
gooseberry	*Ribes sp.*
gooseberry, Trumpet	*R. leptanthum*
Grape	*Vitus vinifera*
grama, Blue	*Bouteluna gracilis*
grama, Sideoats	*B. curtipendula*
grass, Indian	*Sorghastrum nutans*
Hackberry	*Celtis occidentalis*
hawthorne, River	*Crataegus rivularis*
honeysuckle, Amur	*Lonicera maackii*
honeysuckle, Belle	*L. bella*
honeysuckle, Blueleaf	*L. korokowii*
honeysuckle, Muenden	*L. Muendeniensis*
honeysuckle, Rose, tatarian	*L. tatarica cv. rosea*
honeysuckle, Tatarian	*L. tatarica*
hoptree, Baldwin	*Ptelea baldwinii*
juniper, Rocky mountain	*Juniperus scopulorum*
juniper, Singleseed	*J. monosperma*
Kenaf	*Hibiscus cannabinus*
lespedeza, Bicolor	*lespedeza, bicolor*
lespedeza, Korean	*L. stipulacea*
lespedeza, Sericea	*L. cuneata*
lespedeza, Striate	*L. striatelilac*
lilac, Chinese	*Syringa chinensis*
lilac, Common	*S. vulgaris*
lilac, Japanese tree	*S. japonica*
lilac, Persian	*S. persica*
locust, Black	*Rovinia pseudoacacia*
lovegrass	*Eragrostis*
1/	*E. capansis*
lovegrass, Weeping	*E. curvula*
1/	*E. lehmanniana*
1/	*E. plana*
lovegrass, Wilman	*E. superba*
Matrimonyvine	*Lycium halimifolium*
millett, Foxtail	*Setaria italica*
needlegrass, Green	*Stipa viridula*
ninebark, Illinois	*Physocarpus intermedius*
oak, Burr	*Quercus macrocarpa*

1/ No acceptable common name.

Common Name	Scientific Name
olive, Desert	*Forestiera neomexicana*
olive, Russian	*Elaeagnus angustifolia*
Peach	*Prunes persica*
peashrub, Afghanistan	*Caragana decorticans*
peashrub, Boise	*C. boisii*
peashrub, Littleleaf	*C. microphylla*
peashrub, Maximowicz	*C. maximowicziana*
peashrub, Peking	*C. pekinensis*
peashrub, Pygmy	*C. pygmaea*
peashrub, Shrubby	*C. fruticosa*
peashrub, Siberian	*C. arborescens*
pine, Bristlecone	*Pinus aristata*
pine, Ponderosa	*P. ponderosa*
Potato	*Solanum tuberosum*
rabbitbrush, Rubber	*Chrysothamnus nauseosus*
Redtop	*Agrostis gigantea*
ricegrass, Indian	*Oryzopsis hymenoides*
ricegrass, Mandanl	*X. Stiporyzopsis caduca*
rose, Arkansas	*Rosa arkansana*
Rye	*Secale cereale*
sacaton, Alkali	*Sporobolus airoides*
sagebrush, Basin big	*Artemisia tridentata*
sagebrush, Silver	*Artemisia cana*
saltbush, Fourwing	*Atriplex canescens*
salt-tree, Siberian	*Halimodendron halodendron*
sandreed, Prairie	*Calamovilfa longifolia*
Silverberry	*Elaeagnus commutata*
snowberry, Common	*Symphoricarpos albus*
snowberry, Mountain	*S. oreophilus*
snowberry, Utah	*S. utahensis*
snowberry, Whortleaf	*S. vaccinioides*
spirea, Mongolian	*Spirea gemmata*
spirea, Nippon	*S. nipponica*
spirea, Sargent	*S. sargentina*
spirea, Wilson	*S. wilsonii*
Sudangrass	*Sorghum sudanese*
sumac, Skunkbush	*Rhus trilobata*
sweetclover, Yellow	*Melilotus officianalis*
sweetclover, White	*M. alba*
Switchgrass	*Panicum virgatum*
tansy, Common	*Tanacetum vulgare*
Timothy	*Phleum pratense*
Tomato	*Lycopersicon escutentum*
tree, Wayfaring	*Viburnum lantana*
trefoil, Birdsfoot	*Lotus corniculatus*
vetch, Hairy	*Vicia villosa*
viburnum, Manchurian	*Viburnum burejaeticum*

Common Name	Scientific Name
Wheat	*Triticum aestivum*
wheatgrass, Crested	*Agropyron desertorum*
wheatgrass, Fairway	*A. cristatum*
wheatgrass, Intermediate	*A. intermedium*
wheatgrass, Montana	*A. albicans*
wheatgrass, Pubescent	*A. var. trichophorum*
wheatgrass, Slender	*A. trachycaulum*
wheatgrass, Streambank	*A. riparium*
wheatgrass, Tall	*A. elongatum*
wheatgrass, Western	*A. smithii*
wildrye, Altai	*Elymus augustus*
wildrye, Basin	*E. cinereus*
wildrye, Beardless	*E. triticoides*
wildrye, Canada	*E. canadensis*
wildrye, Mammoth	*E. giganteus*
wildrye, Russian	*E. junceus*
Winterfat	*Ceratoides lanata*
wolfberry, Chinese	*Lycium chinese*
wormwood, Common	*Artemisia absinthium*
wormwood, Dwarf oldman	*A. abrotanum subsp. nanum*
wormwood, Mugwort	*A. vulgaris*
yarrow, Fernleaf	*Achillea filipendulina*

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